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PROCESSING OF BULKHEAD SEGMENTS FOR SATURN V VEHICLES

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In Cooperation With Technology Utilization Office
NASA

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ABSTRACT

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Fabrication of gore segments for bulkheads of the S-IC, S-II, and S-IVB stages of the Saturn V has presented many technical problems. This report discusses the production of gore segments for these bulkheads beginning with the aluminum alloy ingot and continuing through final inspection of the individual gore. The usual mechanical processes and heat treatments are presented as well as the chemical operations, such as chemical milling and surface protection.

Sections of this report cover the various detailed processes currently used to form, rework, mechanical mill and/or chemical mill, protect, package, and weld fittings into the gores. Of particular emphasis are the primary forming methods--hydraulic bulge, stretch, explosive, and incremental dish forming--and post-forming operations, such as chemical milling and contour correction.

The recommended use of one forming method in preference to another is not the intent of this report. Thus, the content herein is presented as a historical document which reflects the current state-of-the-art in the forming of large gore segments.

Author

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METHODS DIVISION BRANCH

MANUFACTURING ENGINEERING LABORATORY

FOREWORD

The space oriented research and development programs being performed by and for the National Aeronautics and Space Administration provide a continuous flow of new and sometimes unique technological developments. It is the policy of NASA to give these new developments the widest possible dissemination so that the people may benefit from this vast storehouse of knowledge.

In keeping with its character, the NASA's Administrator established the Technology Utilization program under the Office of Technology Utilization. The technological information is identified by the various NASA field centers from in-house and contractor related projects, screened for possible industrial applications, documented and disseminated to industry.

This document is in direct support of the policy that all new technology gained through the various research and development programs performed by and for the National Aeronautics and Space Administration should be made available to the people. The method of forming of integral ribs by cold press-extrusion techniques described herein is a direct result of techniques developed by a NASA contractor for the Manufacturing Engineering Laboratory of the George C. Marshall Space Flight Center.

Additional information may be obtained from:

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SUMMARY

The manufacturing processes for the gore segments of the Saturn V bulkheads are discussed in detail. The process variations incurred with the two aluminum alloys, 2219 and 2014, are emphasized.

A step-by-step description is given for each stage of manufacturing-- from the materials furnished to the contractors, through the welding of fittings to the finished gore. Summaries are included for preforming machining, forming processes used, chemical milling procedures, post-forming techniques, and handling and storage methods.

Forming procedures are described in detail, including methods considered but not utilized. Special attention is focused upon the methods currently used for manufacturing gore segments. These methods include bulge forming, explosive forming, stretch forming, and incremental dish forming. Chemical milling procedures are also outlined.

SECTION I. INTRODUCTION

The manufacture of gore segments for the Saturn V bulkhead presented several problems which had to be resolved concurrently with the production efforts. This report discusses the production problems, the corrective actions taken, and the current state of the art.

Initially, four methods of fabrication were attempted: (1) incremental dish forming at Pittsburgh Des Moines Co., Birmingham, Alabama, (2) explosive or high energy forming at Ryan Aeronautical Corp., San Diego, California, and North American Aviation, El Toro, California, (3) hydraulic bulge forming at Boeing Co., Wichita, Kansas, and (4) stretch forming at Douglas Aircraft Corp., Santa Monica, California.

Gores for the S-IC are formed by the hydraulic bulge forming process (Boeing) with explosive forming as a back-up process (Ryan); for the S-II by the explosive forming process (NAA) with stretch forming as a back-up (Douglas); and for the S-IV and S-IVB, gores are formed by the stretch forming process with bulge forming as a back-up (Douglas).

Each of the above processes has proved applicable for manufacturing Saturn V gore segments and has been developed to the extent that high quality gores can be consistently produced.

The Saturn V utilizes two aluminum alloys--2219 for the S-IC and 2014 for the S-II and S-IVB stages. The use of two aluminum alloys has restricted the interchangeability of production information. Thus, this investigation is reported in two phases--alloy 2219 and 2014.

SECTION II. ALUMINUM ALLOY 2219 GORES

A. RAW MATERIAL

Aluminum alloy 2219 is processed in the usual manner by the mills. After being rolled to the approximate gage thickness, the aluminum plate is solution heat treated at 995°F and quenched by immersion or spraying with cold water. The material is then rolled and stretched to the desired gage for a total of 7-10 percent reduction in thickness. The resulting material is in the -T37 condition.

Subsequently, the aluminum is 100 percent ultrasonically inspected at 60 percent reduction from ingot for internal defects, in accordance with the Class B standards of Airframe Subcommittee Report No. 1 (Revised) "Recommended Ultrasonic Standards for Airframe Aluminum Alloy Plate," published by the Society for Non-Destructive Testing. Ryan Aeronautical Co., San Diego, California, purchases the aluminum plate in accordance with MIL-A-8920A (Aluminum Alloy Plate and Sheet), while The Boeing Co., Wichita, Kansas, and Michoud, purchases the plate in accordance with BMS-7-105C (2219 Aluminum Alloy Sheet and Plate).

Tensile tests are conducted on samples cut perpendicular to the direction of rolling and machined from material midway between the plate surfaces. The chemical composition is also determined. All data is recorded and placed in a folder to accompany each piece of material throughout processing. Subsequent tests and checks are also recorded and included in the folder.

Aluminum alloy 2219 is susceptible to corrosion because of the high copper content. Thus, protection from the weather at all times is an absolute requirement. Prior to packaging in accordance with MIL-A-20695, the material is wiped with a preservative petroleum oil. This permits storage up to six months in an enclosed warehouse. Other treatments required for later processing of the material will be discussed in the sequence in which they occur.

B. BLANK PREPARATION

Upon receipt of the raw stock at Boeing-Wichita, the plate is removed from the crates and visually inspected for scratches and mechanical damage. Samples are removed from the trim areas for tensile tests and metallurgical analysis to verify the vendor's data. Stress corrosion tests are also conducted. Having satisfied the basic material requirements, each sheet is stamped with a code number which is retained throughout processing. The sheets are stacked with 2-inch wooden spacers to await further processing.

Gore segments to be formed by the bulge process may be processed in either of two ways--constant thickness or presculptured. For either type, the gore blank is milled on a Kearney-Trecker skin mill, having a capacity of 12 ft. by 80 ft. Constant thickness gores were found to thin out at the center, and caused the gores to be under the thickness tolerances. To overcome this difficulty, gore blanks are machined slightly thicker (by 0.005 - 0.010 inch) in the center. Consequently, when the thinning occurs, the part is within desired tolerances. Thicknesses are checked with a Vidigage. All panels have approximately 0.100 inch minimum removed from each side to eliminate surface defects.

Gores for configuration S-IC-T have lands for bosses and welds; therefore, these gores can be bulged from pre-sculptured blanks or chemically milled to final contour, or a combination of both. Portions of the panels have different amounts of stretch because of the varying thicknesses. For this reason, the contour which must be milled into the plate is extremely difficult to predict so that the panel stretches to the desired finished pattern. A trial gore is formed, and afterwards necessary changes are made in the preform.

The scrap rate estimated by Boeing for the mechanical milling process is 1 percent for base and 1 percent for apex segments. The aluminum blanks were rough trimmed by a skill saw for the bulging operation but are now purchased to fit the dies.

After machining, the panels are hand finished to blend in all radii and to remove burrs which occurred during the machining operation. Using a Bertsch pyramid roll, the panels are rolled to a radius of approximately 195 inches. The part is ready for bulge forming after the panel is machined, checked for thickness and rolled.

Ryan Aeronautical Company explosive forms only constant thickness blanks. Like BAC, the blanks are trapezoidal as delivered. For apex segments, tabs are welded to the base corners and trimmed, since plate widths exceeding 132 inches are not available. Approximately 0.100 inches is removed from each side by skin milling. Tolerances are ± .005 inch with a 63RMS surface finish. Scrap rate is reported to be 10 percent, unless the blanks can be re-milled, in which case the scrap rate could be as low as 2 percent.

Ryan's trimming operation consists of scribing the part with a template and hand sawing with a pneumatic saw with carbide inserts. The blanks are pre-rolled on a Pope Roll having a capacity of 3/4 inch hot rolled steel plate by 12 feet wide.

C. GORE SEGMENT FORMING OPERATIONS

1. Hydraulic Bulge Forming

Basically, hydraulic bulge forming consists of forming the aluminum material with a concave die by applying hydraulic pressure directly to the part.

The aluminum stock is rolled to one curvature and placed on the lower die member which contains the piping and fittings for supplying the high pressure fluids. The upper concave die is placed over the workpiece and the two die halves are firmly clamped together around the edge. The two dies have serrated edges which grip the workpiece material, causing the metal to stretch when pressure is applied. Fluid is pumped upward into the area beneath the material until it seats firmly against the concave portion of the upper die. After movement of the part has ceased, the pressure will be raised an additional amount (from 450-1000 psi) to assure complete conformity to the die (Fig. 1).

The Boeing Company uses the hydraulic bulge forming process to form all their gores. Two special fabricated, steel, hydraulic bulging machines had to be designed and built because ot the large size gore sections (115 inches by 230 inches for the base segment blank and 144 inches by 210 inches for the apex) (Fig. 2). Each base die consists of a steel weldment containing a pocket in which initially a cured Neoprene synthetic bag was placed to contain the forming fluid. The bag leaked excessively and has since been replaced by a simple V-shaped pressure energizing seal to allow the fluid pressure to be exerted directly on the workpiece. The upper die is also a steel weldment having a cavity into which the material is pressed to form the finished shape of

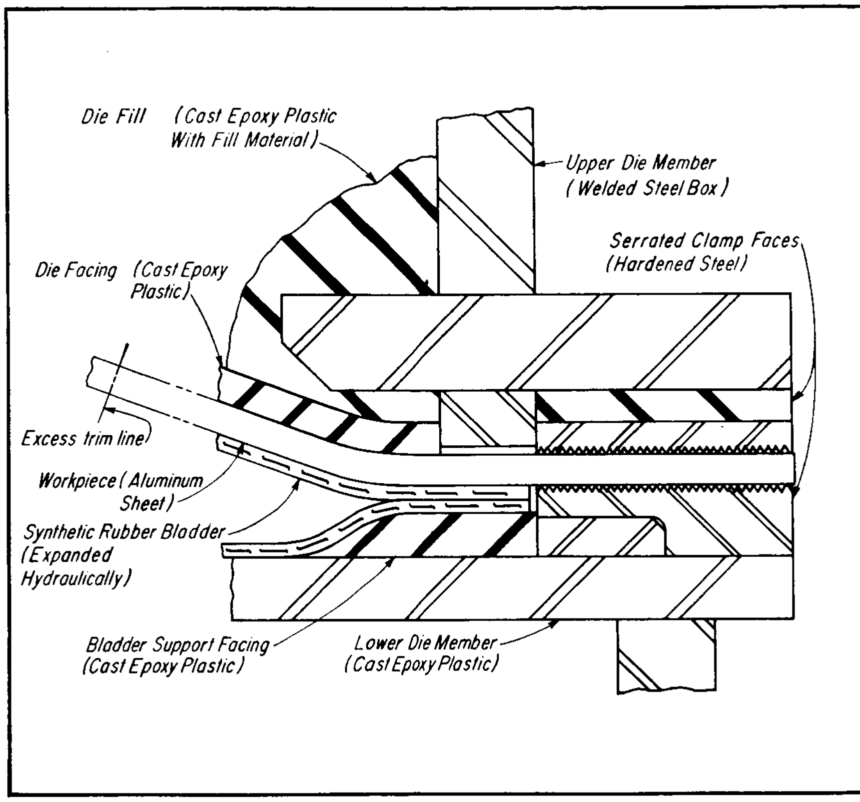

FIGURE 1. SCHEMATIC OF BULGE FORM PROCESS

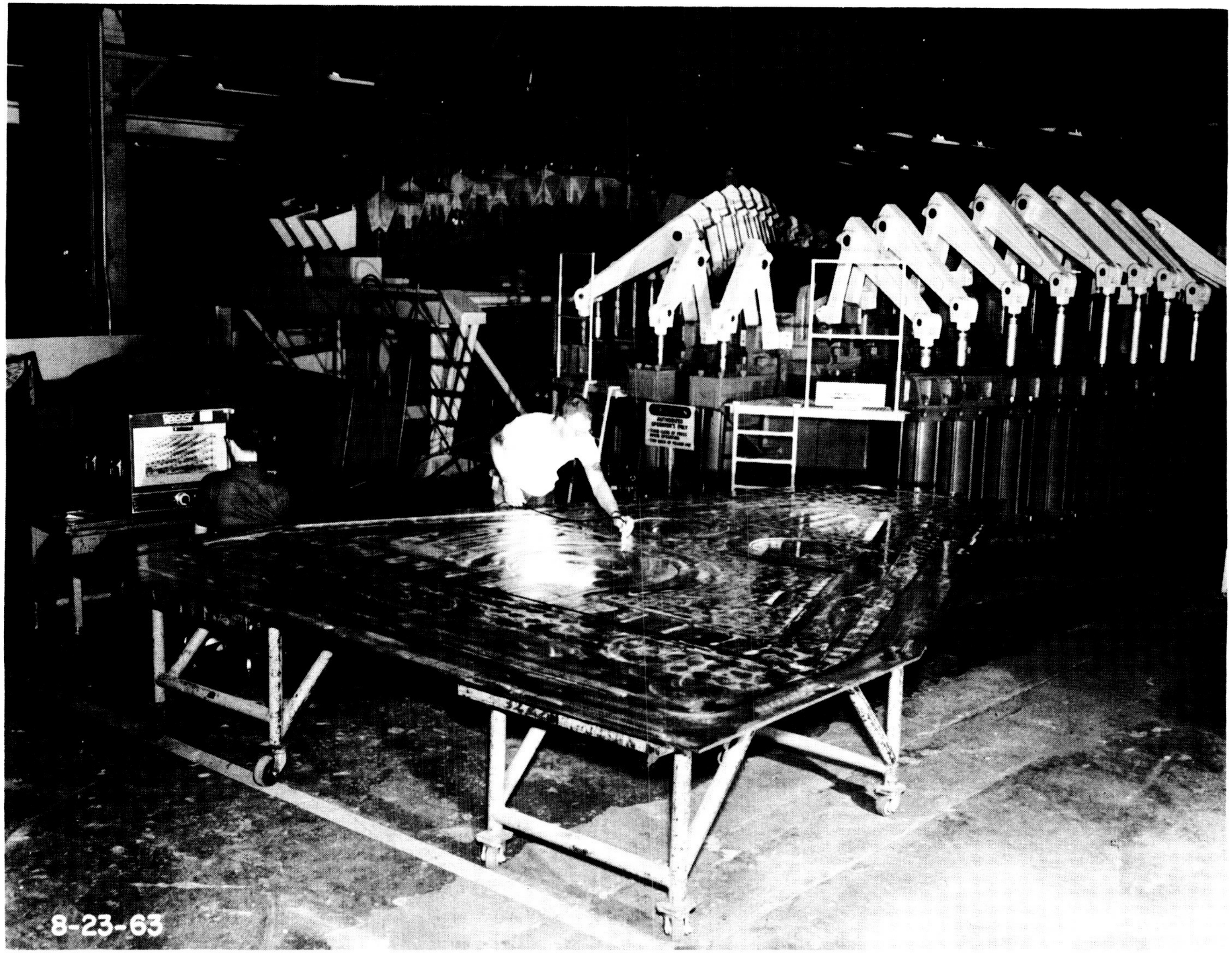

FIGURE 2. BULGE FORMING MACHINE AND BLANK-APEX

the gore. The concave dies were designed to allow for 1 inch of overform, thus compensating for normal springback which occurs in this type of forming operation. A series of hydraulically actuated clamps is mounted around the four sides of each of the two lower dies to hold the upper section of the bulging unit against the base. The frame for the base section has 15 cylinders along the top and bottom and four on each end for a total of 38. The frame for the apex section has 13 clamps on each side--2 on the small end and 6 on the large end, for a total of 34.

The bulging machines are designed to withstand 1500 psi pressure, and a maximum force of approximately 33 million pounds is available for forming the base gore sections. Hydraulic controls for each machine are interlocked so that (1) pressures greater than 1500 psi cannot be applied for forming, (2) pressure cannot be built up in the forming cavity until full pressure is applied to the clamping cylinders, and (3) pressure in the clamping cylinders cannot be released until the forming pressure is released.

Since the bulging units are designed to be used alternately, they have a common hydraulic console and pumping system. The hydraulic clamping system has a 20 hp pump that can deliver 90 gpm at 200 psi for fast filling and 6.96 gpm at 5000 psi for clamping pressure. A 50 hp pump furnishes 28 gpm for bulging the parts. A forming technique for each gore pattern released for production was developed by a R&D group and is based on the thickness of the part, as well as the size and location of the weld lands and bosses. Variables in the process are (1) pressure of side clamps, (2) pressure of end clamps, (3) controlled slip of the part between the clamps, (4) forming pressure, and (5) presculptured dimensions.

The contour pattern of the sculptured blank is determined by trial and error. The best estimate, based on calculations and previous experience, is machined into a blank. Usually only two blanks are required to establish the different variable combinations to develop a production process. Some parts, especially the thinner sections, must be permitted to slip into the cavity and then stretched to the final shape. To accomplish this sequence, shims of 2024 aluminum 4 inches wide by .032 inch thick are placed along surfaces that must be gripped. This arrangement causes the gripping serrations to loosen elsewhere. To prevent distortion of the die, a strip of the same gore thickness, together with two shims, is placed in the clamps. Thus, the clamps have some metal to close on without distorting the die. A hole is drilled through the width of this strip, through which an indicator rod is inserted. The rod is pushed through the hole until it contacts the edge of the blank. Forming pressure is applied to the blank causing the part to draw into the die. The amount of draw is determined by the amount the rod slips in. At a pre-determined draw, pressure is released, the part is clamped all around and forming is completed in pure stretch. Sheets of Teflon approximately 0.010 in thick are placed at points in the die where lubrication is needed to provide slippage.

Holes may be cut in the part where fittings are to be welded, allowing the material to stretch more easily. The holes are cut to a developed elliptical shape and stretched to a desired circular shape. They are also cut undersize to allow later machining to the desired diameter. During forming, the holes must be plugged with metal plates and seals to prohibit leakage of the forming fluid through the openings. Figure 3 illustrates a typical BAC forming procedure.

A four-man crew is required to load and unload the machine. Each part requires approximately 21 manhours for preparation and loading of the blank, and approximately four hours for forming the part. Actual forming time varies from 30 minutes to 2 1/2 hours. Scrap rates generated to date are approximately 2 percent for sculptured panels and 1 percent for constant thickness panels. The constant thickness panels are .195 to .830 inch for the apex and .224 to .730 inch for the base.

The difficulty of predicting the amount of draw of a presculptured blank is a source of continuous problems. Experience, accuracy of setup and preform contour, and considerable care during forming can allevaite these problems (See Table I for R&D work accomplished to date).

2. Explosive Forming

Ryan Aeronautical Company employs explosive forming for S-IC gore segments. As of January 1, 1964, this development had not been completed.

Ryan's explosive forming dies are shown in Figures 4 and 5. These dies are composed of massive ribbed SAE 1030 steel castings, with the die surface having a minimum 7-inch thickness at any point. Two holes are located at the bottom of the die to draw away the air between the part and the die. The vacuum seal is placed in the slot around the outer edge. The dies are machined to net contour.

TABLE I. BULGE FORMING R&D ACCOMPLISHED THROUGH MARCH, 1964 AT BOEING-WICHITA

Constant thickness apex (chem-milled after forming)

Nominal Thickness	.195
	.264
	.270
	.350
	.359
	.407
	.410
	.462
	.500
	.608
	.830

Constant Thickness Bases (chem-milled after forming)

Nominal Thickness	.224
	.264
	.270
	.407
	.410
	.500
	.608
	.650
	.730

Machined Sculptured Apex -	*	Part No.	60B24212-1
	*		60B24212-2
	*		60B24209-1
	*		60B12102-1
	*		60B12202-1
	**		60B24210-1
	**		60B24211-1

Machined Sculptured Bases -	*	Part No.	60B24105-1
	*		60B12106-1
	**		60B24105-3

* Fully developed and excluded from the chem-mill program.
** Fully developed but not excluded from the chem-mill program.

R&D accomplished on Weld Certification Panels for Michoud.

Apex 60B24103-3
Apex 60B24104-1
Apex 60B12105

R&D Planned (R&D temporarily suspended until March, 1964)

Apex 60B24208-3	Base 60B24226-1
Apex 60B24103-1	Base 60B24226-3
	Base 60B12116-1

60B24107-1 GORE APEX - S-IC-S
NO FITTING - UPPER HEAD - FUEL TANK

RECOMMENDED PROCEDURE

A. Machining:

1. Machine part per Engineering using thinout and elongation information gained by TMLO from formed sculptured parts. Use shims to control thinout. (K&T Machine.)

B. Forming:

1. Apply grid lines and Vidigage.
2. Lubricate outer surface and apply clay balls.
3. Allow draw on bottom or wide end using following method:
   (a) Apply shims .032" X 4" wide 2024-T both sides of part in Area "A".
   (b) Remove 1½" wide strip from bottom of part in Area "B".
   (c) Drill 1/8" dia. hole in center of 1½" strip (Area "B") for measurement of feed-in.
   (d) Install 1½" wide strip with .032" X 1½" wide 2024-T shim, both sides of strip (Area "B").
4. 1800 PSI minimum clamping pressure all cylinders.
5. Apply water pressure until indicator rod at Area "B" shows a draw on 1 1/8". Raise upper die member and remove all .032" thick shims.
6. Apply 450 PSI minimum water pressure.

C. Checking:

1. TMLO check part as necessary for deviation from Engineering (for tape correction and thinout shim adjustment).

NOTE: The above procedure applies to 60B24107-1 only.

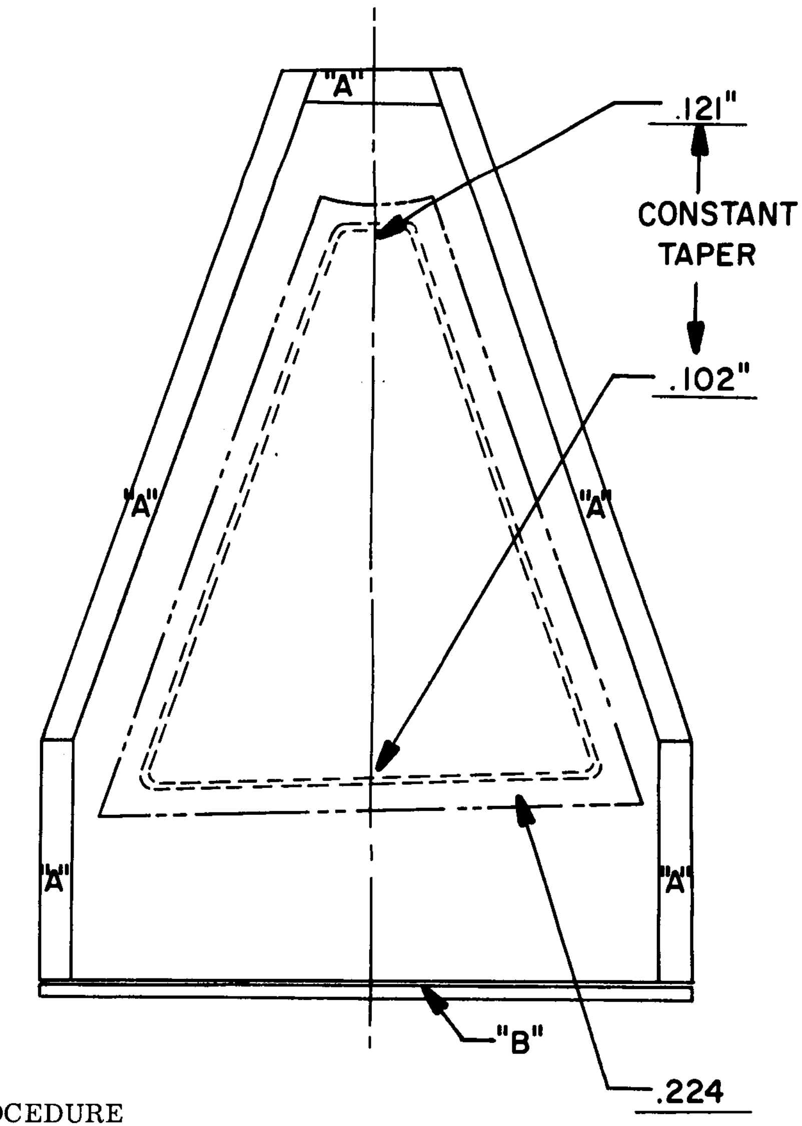

FIGURE 3. BOEING FORMING PROCEDURE

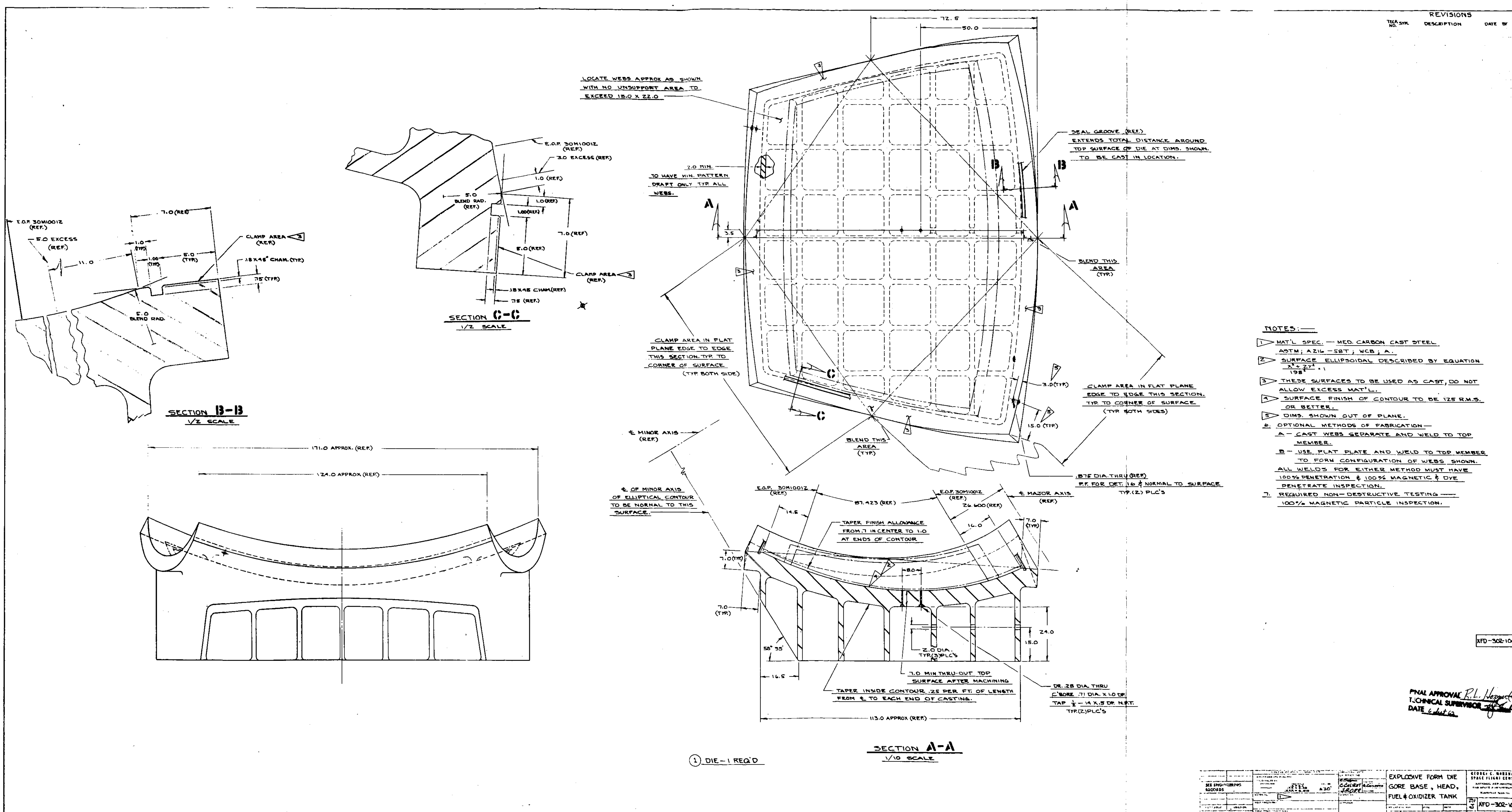

FIGURE 4. EXPLOSIVE FORM DIE-GORE BASE

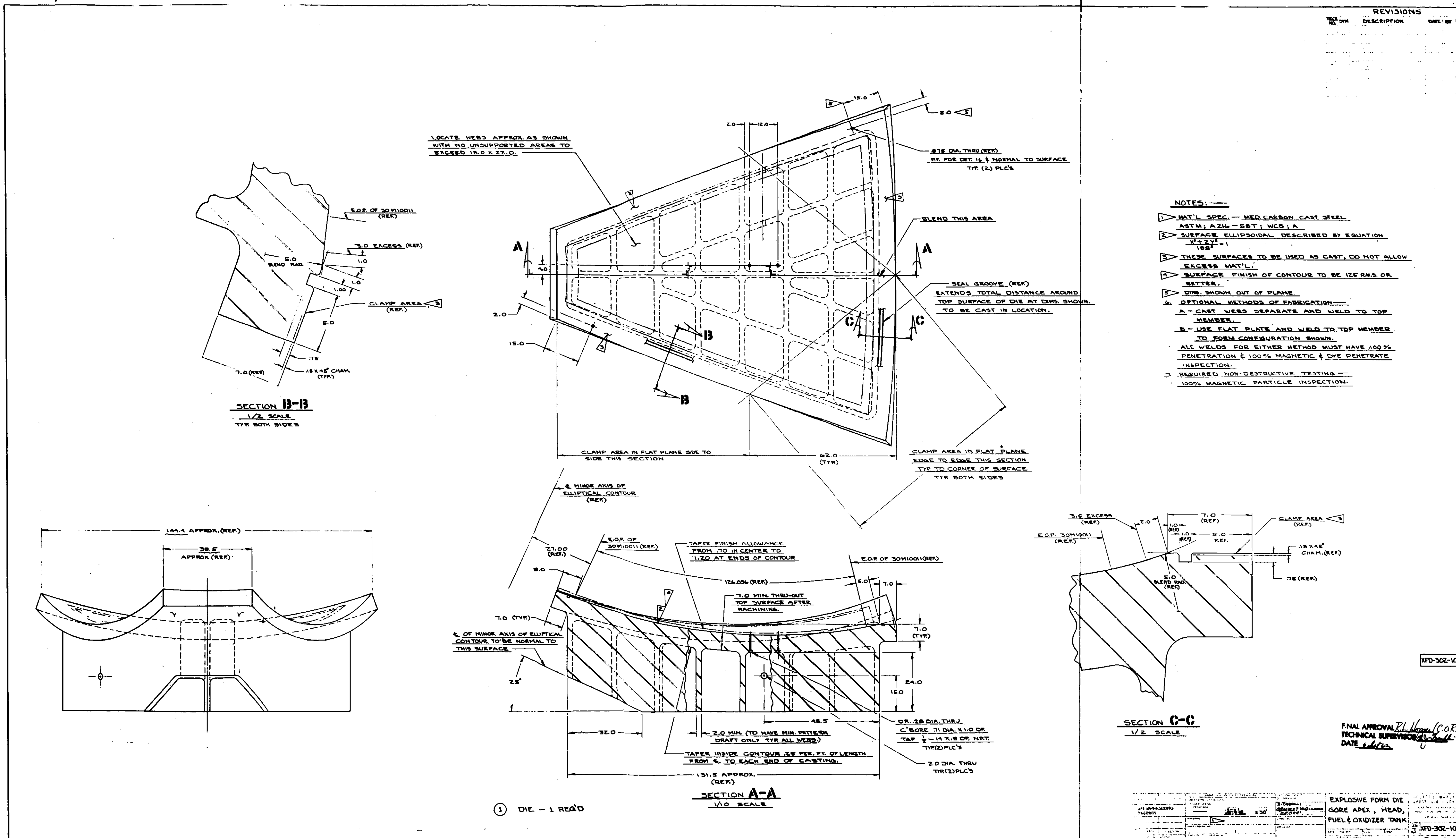

FIGURE 5. EXPLOSIVE FORM DIE-GORE APEX

A series of explosive shots is required to form a part. The first shots achieve a rough approximation by pressing the material down toward the bottom of the die; the final shots seat every portion of the workpiece material into the die. A typical series of shots used to form an apex segment is:

Explosive--200 gr/ft. Primacord, totaling 135 lineal feet, and DuPont sheet explosive.

1st Shot--12 feet of 200 grain Primacord and sheet explosive 4 inches by 16 inches, 30 inch standoff (Pressure applied to middle of sheet).

2nd Shot--24 feet of 200 grain Primacord and sheet explosive 4 inches by 16 inches, 16 inch standoff (Pressure applied to middle and edge of sheet).

3rd Shot--54 feet of 200 grain Primacord, 12 inch standoff, blanket pressure over the entire gore segment.

4th Shot--45 feet of 200 grain Primacord, 12 inch standoff, blanket pressure over the entire gore segment. Between each shot a visual inspection is made of the clamp ring, die, and vacuum systems to determine suitability for the next shot.

The dies shown in Figures 4 and 5 have been altered considerably since the figures were made. More clamps have been added and further improvements are being studied. Trimming the neoprene rubber blanket so that only the edge is under the draw ring has improved clamping. A newly developed draw ring around the edge of the die has been fabricated from lead (Fig. 6 and 7). A permanent shim will be made of Kirksite or steel.

A minimum stretch of 3 percent is desired, which is the approximate value at which springback becomes predictable. Four self-locking clamps of the type utilized in tensile test have been affixed to each die, one on each side, to prevent excessive slippage. These clamps grip to metal so tightly that slippage is minimized, causing more stretch and a more predictable finish contour.

3. Incremental Dish Forming

Incremental dish forming is used only as a backup system for forming S-IC gores. This process has been used to form panels needed at an earlier date than they could be supplied by Boeing and Ryan because of short lead time and great adaptability. Incremental dishing consists of pressing the aluminum plate between convex and concave tools, a small area at a time.

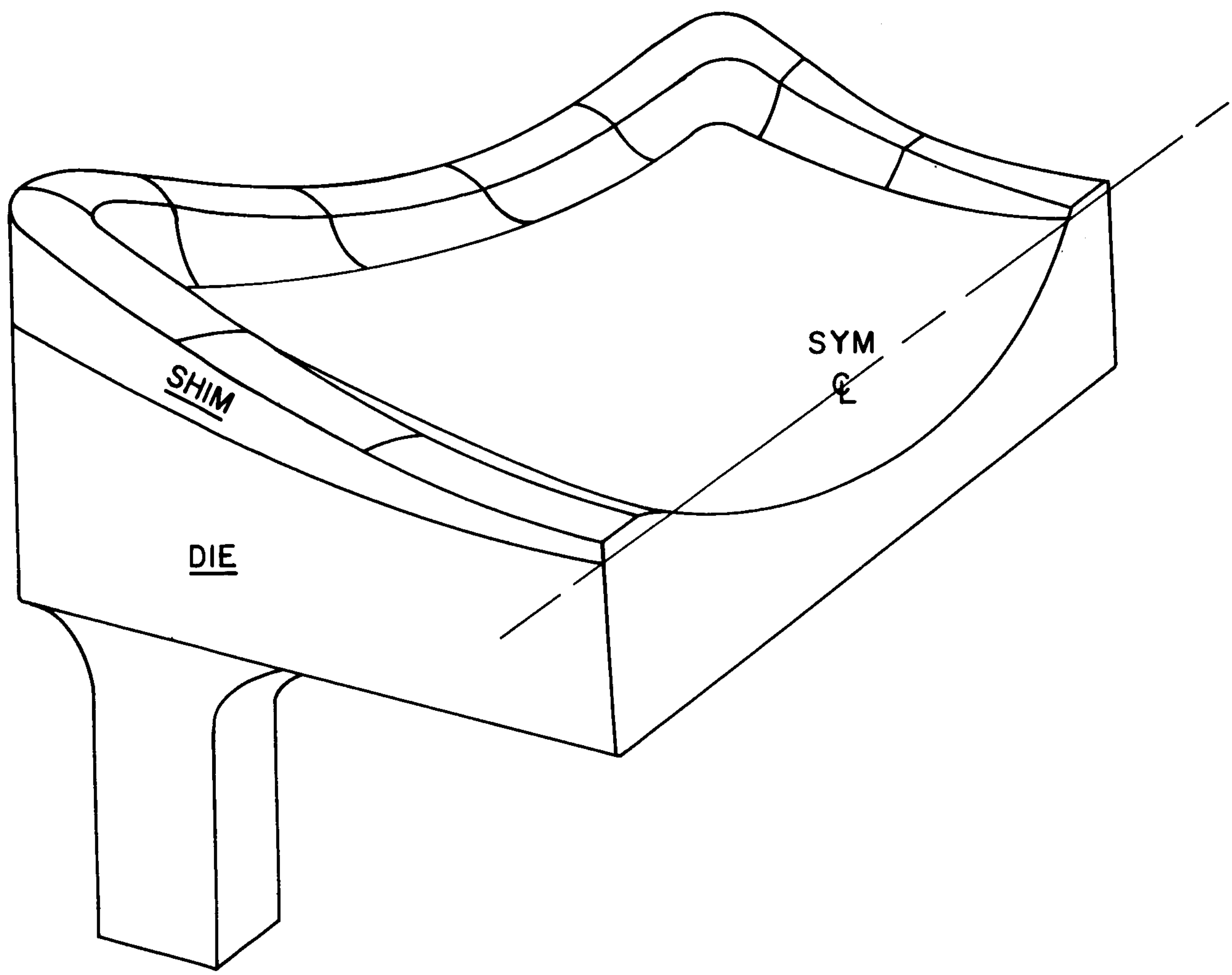

FIGURE 6. SHIM FOR BASE GORE DIE

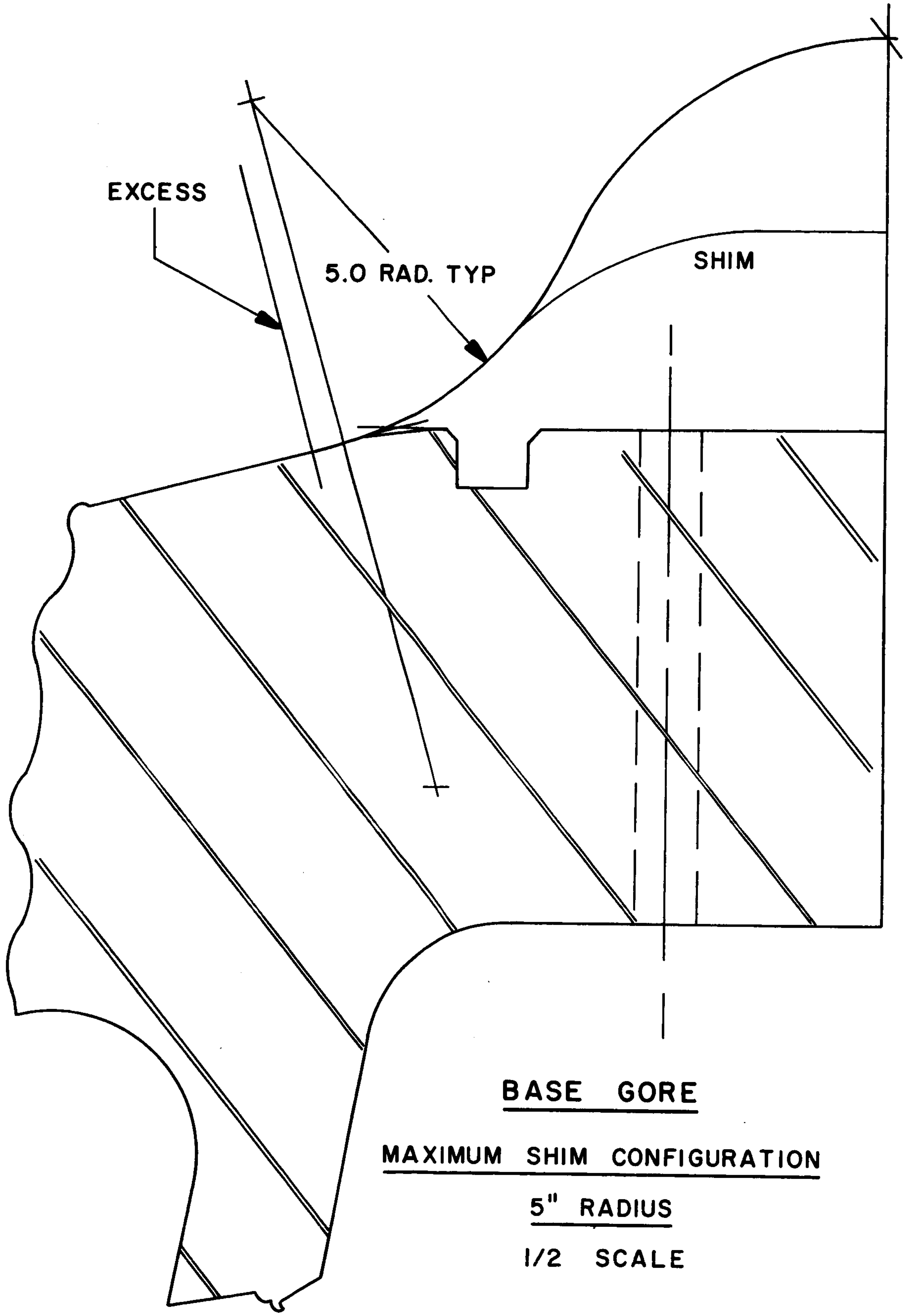

FIGURE 7. CROSS SECTION OF DRAW SHIM

Tooling requirements and associated equipment required are shown in Figure 8. C-frame hydraulic presses, such as shown in Figure 2, are standard in the heavy tank industry and are readily available in capacities up to 1200 tons. The particular press used in the S-IC program is located at the Pittsburgh-Des Moines Steel Company, Birmingham, Alabama, and has a capacity of 200 tons. An overhead crane is essential for large segments. Two sets of forming blocks, approximately three feet in diameter, are required (Fig. 9). The addition of fiberglass facings and the use of the sharpest radius convex tool with the same convex dies has reduced tool changeover time from two hours to ten minutes.

Gore segments formed by incremental dishing met all design requirements on contour, and several parts were used in the S-IC fuel test tank bulkhead. The following tools were used to produce the S-IC gores.

1. Fiberglass facings, dishing (5 feet - 0 inches radius, male and female).

2. Fiberglass facings, dishing (6 feet - 0 inches radius, female only).

3. Fiberglass facings, dishing (8 feet - 0 inches radius, female only).

4. Fiberglass facings, rolling block (8 feet - 0 inches by 5 feet - 0 inches dual radius, male and female).

5. Edge restraining angles, first and second contour sets (to fit all sides of gore segment in pairs, top and bottom, 2 inches by 2 inches by 1/4 inches).

6. Angle clamps (equally spaced, 18 inches apart).

7. Contour templates (sweeps), as required to check contours.

These tools and equipment are generally standard in industry and require minimum modification for variation in contours. A series of spacers is used in conjunction with the forming blocks to vary the degree of forming, as required. Edge restraining members are used in forming thin materials to avoid edge wrinkling. Heavier gage materials have sufficient rigidity to resist wrinkling. Edge restraining members can be formed from angle iron and are preformed to interim component contours as necessary. Two edge restraining members were required on the base S-IC gore, while only one was necessary for the apex.

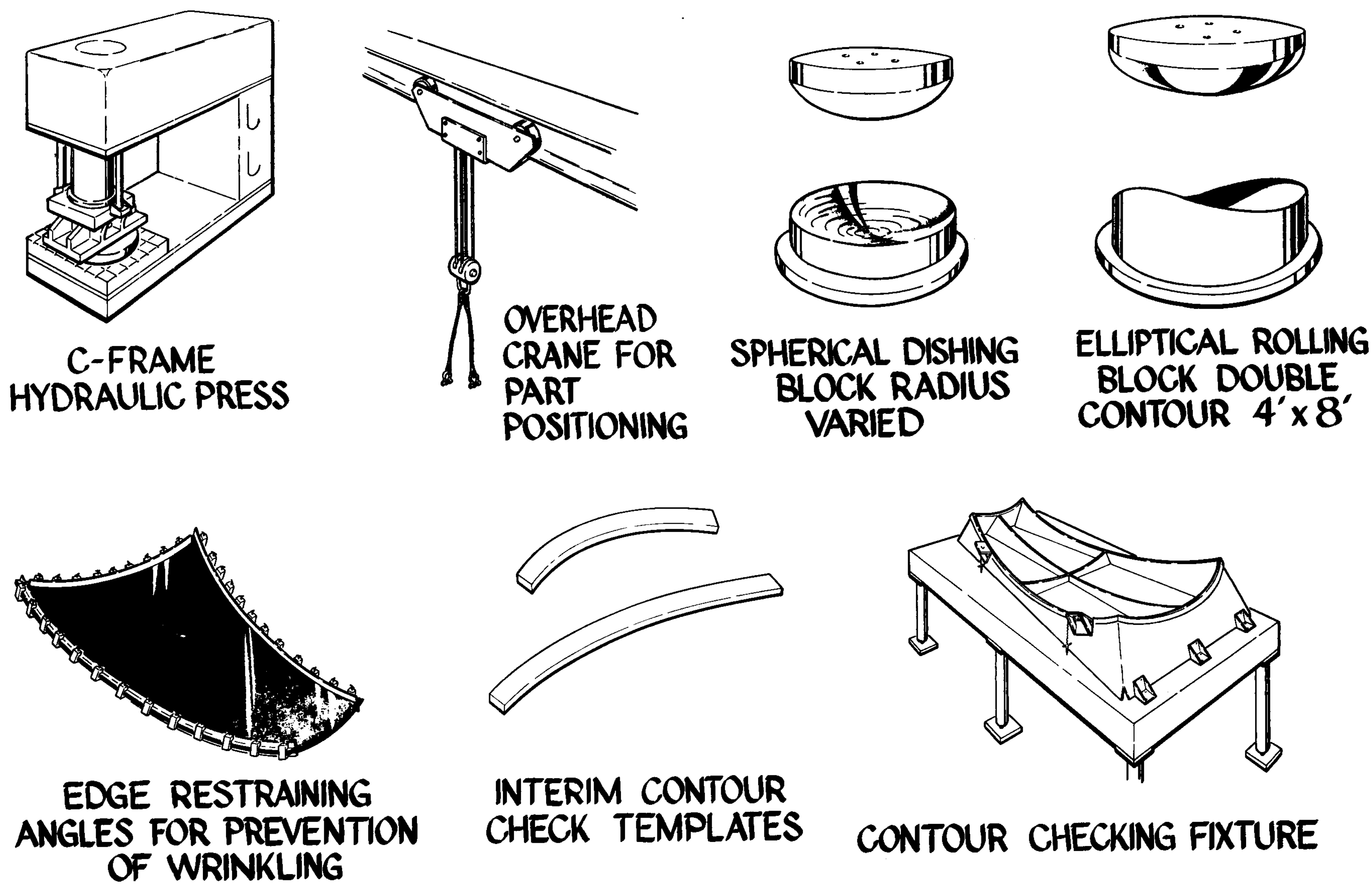

FIGURE 8. ELEMENTS OF INCREMENTAL DISH FORMING

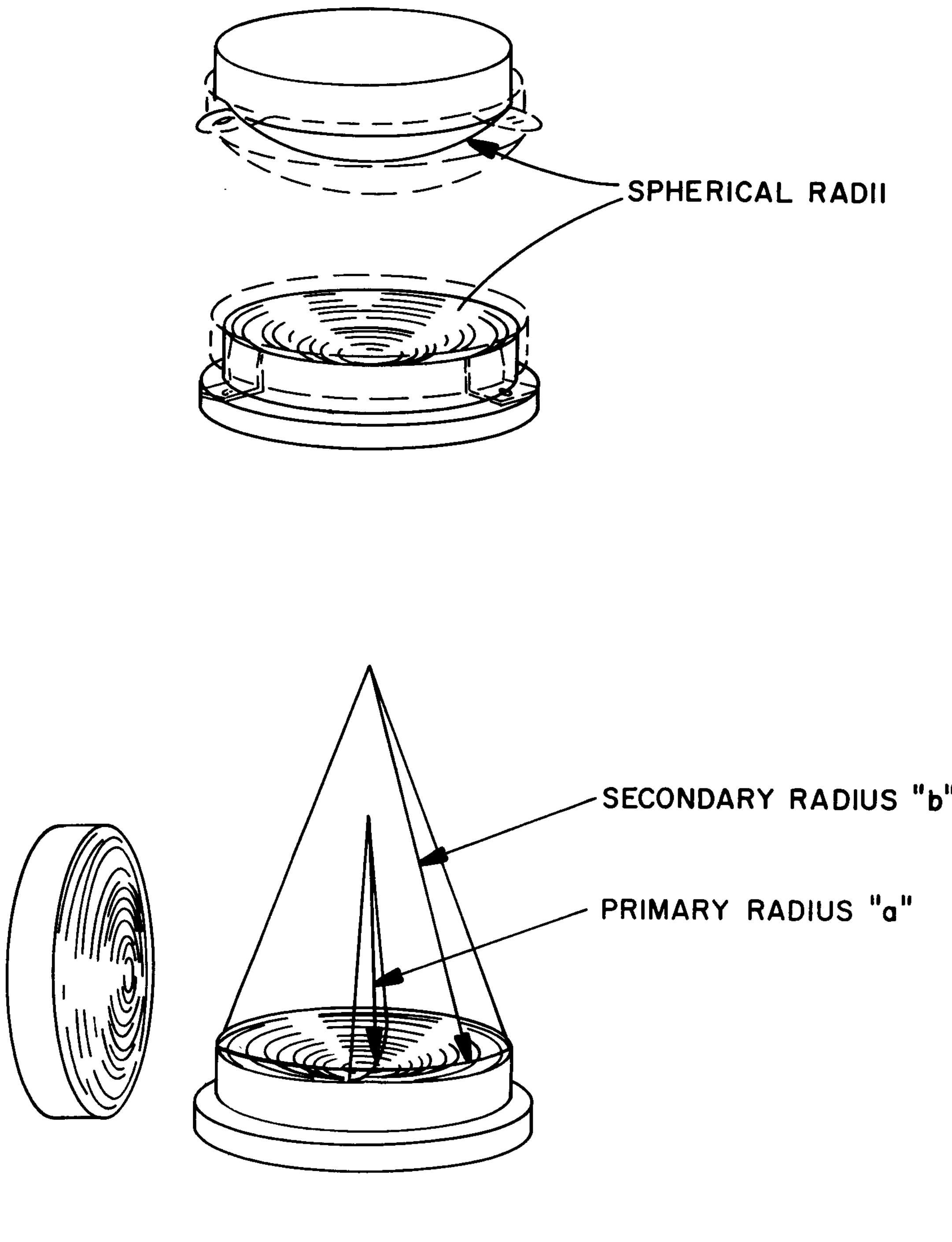

FIGURE 9. FORMING BLOCK FOR BUMPING

Contour templates are required for interim process controls to assure proper contour development and establishment of final contour.

4. Other Methods

a. Androforming

Androforming is a process of forming sheet metal into an infinite number of compound contour shapes, using a single set of adjustable dies called forming elements.

The Androforming machine consists of four major components: (1) the loading table, (2) The forming stages, (3) the drawing mechanism, and (4) the cam tracer (Fig. 10). The material is gripped by the jaw carriage, the forming stages are closed, and the material is drawn through the forming stages which contour the part.

The Androform process produces contours in the same manner as a ribbon is curled by pulling between one's finger and thumb. Cams may control the gaps between forms to produce an assymetric contour. To date, no Saturn V gore segments have been formed by this process.

b. Shot Peen Forming

In shot peen forming, steel shot are driven against one face of the part. The impact of the shot causes the surface to spread, creating compressive stresses on the opposite surface. Unbalanced forces within the part cause it to curve. This process improves the fatigue strength of the part by eliminating areas of tensile stress concentration on the material surface.

The material is fixed to a table which is tilted to allow the shot to fall away from the work area. The shot is propelled by compressed air through nozzles, which are contained in a traveling carriage which passes over the part. The forming process is controlled by varying the size of shot, air pressure, and the length of time that the section is subjected to the spray of shot.

This process was unsuccessfully used in an attempt to correct minor contour discrepancies on Saturn V gore segments.

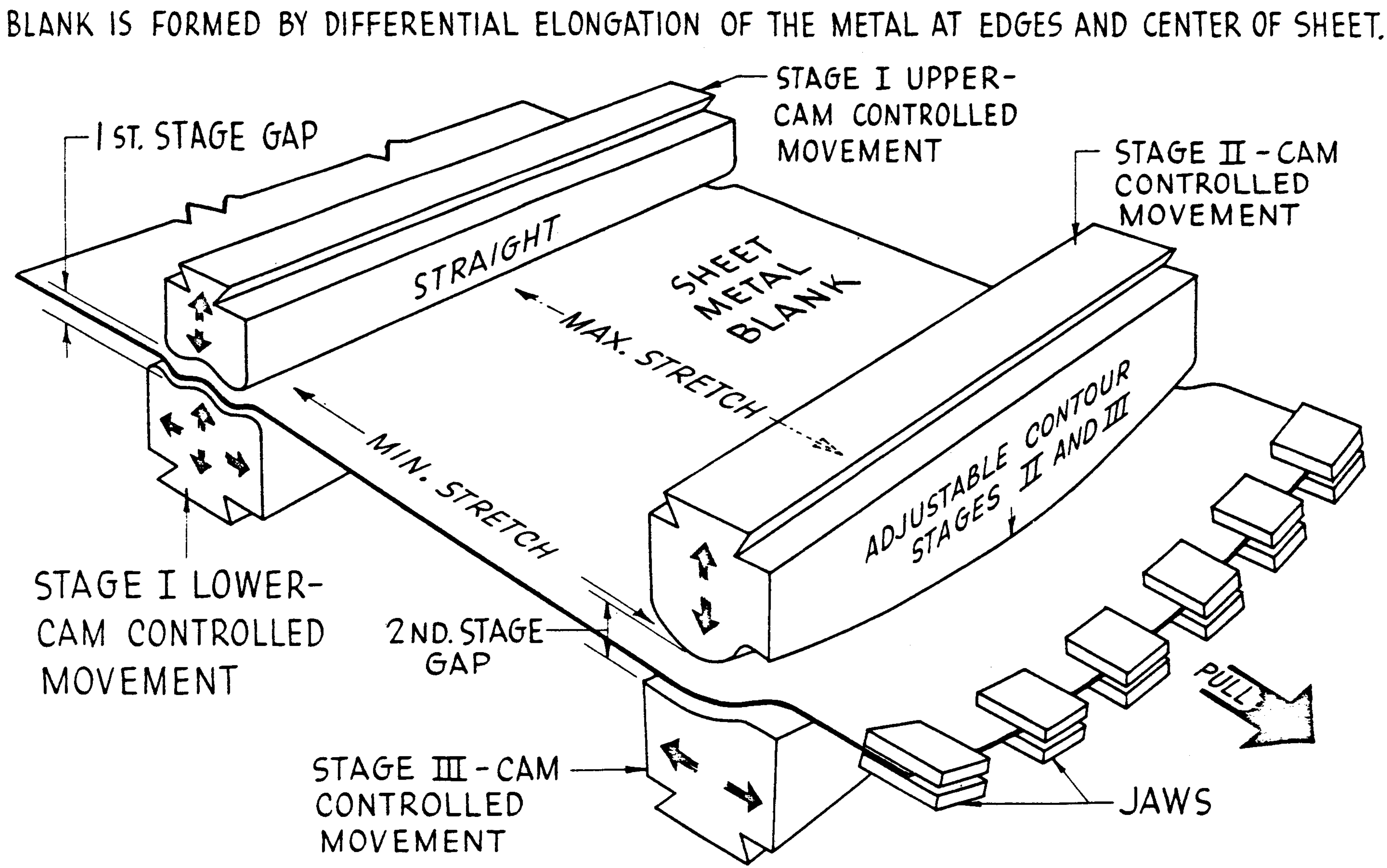

FIGURE 10. ANDROFORM PRINCIPLE

c. Press Forming

Tooling for press forming consists of a full size concave die with a matching punch. The material is laid over the die and the punch is advanced to press the part into the cavity of the female die. This operation is similar to the familiar punch press operation but on a much larger scale. No Saturn V gore segments have been formed by this process.

d. Stretch Forming

In stretch forming, the blank is gripped by two jaws and subjected to a tensile load sufficient to exceed the yield strength of the material. A formed mandrel is advanced into the surface of the material producing the desired contour. This process, as used by Douglas Aircraft Corporation on Saturn V gore segments, will be explored more fully in Part II.

e. Explosive Stretch Forming

Explosive stretch forming consists of forming the metal over a male die by explosively forcing the periphery of the material downward (Fig. 11). This process has the advantage of stretch forming in that center sections do not thin out during forming. After forming, the part is cut from the center of the blank; the remaining material is scrapped.

D. GORE SEGMENT TRIMMING AND SIZING

1. Trimming

The formed gores are placed upon a concave fixture for scribing. After all forming and contour correction is complete, tooling holes are drilled in the periphery of the part to MSFC NASA requirements. The parts are removed from the fixture and edge trimmed to rough size, which is usually net plus 3 inches.

2. Contour Correction Forming Methods

a. Age Sizing

All gores are age sized either by MSFC, or in the case of gores supplied in the -T87 condition, by the vendor. Age sizing consists of restraining the part in an aging fixture during the aging cycle. The restraint may hold the part to net contour or to an over contour. Gores which will later have fittings welded into them at MSFC or Boeing Michoud are supplied in the -T37

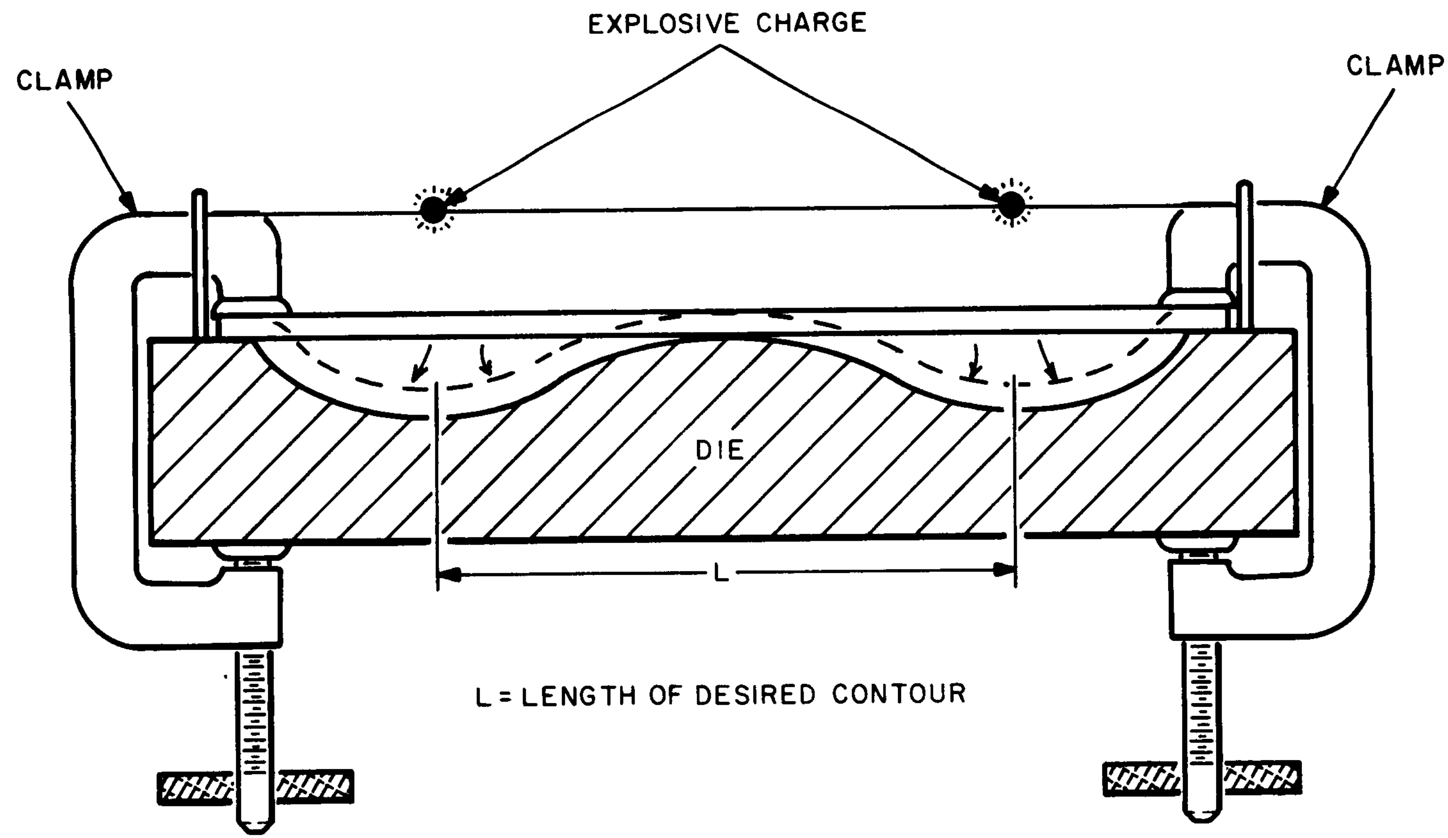

FIGURE 11. EXPLOSIVE STRETCH FORMING

condition. After being welded, the gores are aged to the -T87 temper or equivalent in a restraining heat treat fixture which provides correction of contour up to 90 percent of forming or weld distortion.

b. Explosive

Ryan uses explosives for correction of contour. Chemical milling can induce contour deviation and an explosive rehit can be employed to bring the contour to the desired tolerance.

c. Incremental Press

Incremental pressing may be used to correct deviations of almost any magnitude. Stock severely damaged in handling or shipping may often be salvaged by this method. This is the same method as described earlier. Boeing uses a variation of this method to correct contours. The forming dies have been replaced by a setup giving simple three point loading for local contour correction.

d. Stress Relief

Stress relieving consists of correcting the contour during a stress relief operation in a restraining fixture. This method was abandoned because it severely limited the capability of age-sizing to remove weld distortion at MSFC.

E. CHEMICAL MILLING OF FORMED SECTIONS

1. Requirements

Both waffle patterns and stepped patterns are designed for the S-IC gore sections to give sufficient strength with a minimum weight. A typical thickness tolerance is +0.015 to -0.000 inch, with a required surface finish of 125 microinches RMS maximum.

2. Chemical Milling Process

Initially the gores are cleaned in the following sequence: (1) vapor degreased, (2) alkaline cleaned, (3) rinsed, (4) deoxidized, (5) rinsed, and (4) dried. After the burrs and sharp edges are removed, several coats of a chemically inert maskant are applied to clean the metal surface. Ryan uses a translucent neoprene base maskant, while Martin-Denver utilizes a black neoprene maskant. The final curing is accomplished by allowing the maskant to dry at ambient temperature for 12 to 24 hours, depending upon the relative humidity.

After curing, the chemical milling pattern is scribed into the maskant utilizing a template to insure accuracy. The maskant is removed from areas to be milled by carefully pulling from the edge to the center of the scribed area. All foreign matter and maskant residue are wiped from the bare metal surface with solvent. Caution must be exercised to prevent the solvent from coming in contact with the remaining maskant. Lead tape is applied over the edges of the maskant for protection from handling.

The 2219= T37 gores are chemically milled in a solution of 13 ounces of Turcoform etchant 13, and 5 ounces of Turcoform Alketch Inhibitor per gallon of solution at 190 ± 5° F. The etchant concentration is maintained above 11 ounces per gallon, and the inhibitor does not exceed 20 ounces per gallon. Every 30 to 45 minutes the gores are removed from the etchant, rinsed, de-smutted, and rotated 180 degrees in the vertical plane before returning them to the etchant. The rotation of the gore reduces the agitation and concentration differences within the tank.

The heavy black smut, which forms during chemical milling, is removed by submerging the gores in a chromic acid desmutting solution for approximately 10 minutes, or until all smut is removed. The gores are finally rinsed and dried at ambient temperature. The maskant is manually removed from the panel. Initially the maskant can be loosened by subjecting the masked gore to the vapor degreaser. Sludge or smut remaining after demasking is completely removed by repeating the desmutting procedure above.

3. Problem Areas with 2219 Gores

Rough surface finish (approximately 200 RMS) was a problem in early development work, but this problem has been reduced significantly by the use of a high sulfide type etchant, Turcoform 13.

Apparent differences in chemically milled panels existed; however, most of these problems have been corrected by varying the concentration and temperature of the etchant. Several scaling problems were experienced, namely from beaker scale to a 225-gallon tank and then to the 13,000-gallon production tank.

Thickness variations in the chemically milled gores, 0.040 inches to 0.050 inches, are presently causing concern. Areas of the gore are being etched at different rates causing randomly spaced high and low areas. This situation is undesirable because of the added weight to the vehicle. Two methods which have been used to obtain specified tolerances are: (1) Manual sanding, and

(2) selective etching of high areas; however, both of these methods are time consuming and expensive. Currently, this problem is being investigated from a metallurgical as well as a chemical standpoint.

4. Future Development Programs

As the weight of the S-IC vehicle becomes more critical; the tolerances held in chemical milling 2219 alloy gores will probably also become more stringent. New etchants and/or effective chemical sizing operation may become necessary if the tolerances on the end product are to be met.

Residual stress redistributions during the chemical milling operation induces possible distortion of formed parts. The feasibility of chemical milling from both sides of the gore segments to minimize distortion will be investigated.

5. Inspection of Chemically Milled Gores

The inspection criteria necessary to determine the quality or acceptability of a processed gore are the resulting surface finish and the dimensional tolerances. The thickness is usually checked with a Vidigage and a tolerance of +0.015 to -0.000 of an inch is required for the S-IC gores. Instruments utilized to measure the maximum surface roughness (125 RMS microinches) are a Profilometer, Talysurf, or Surfindicator.

F. PROTECTION, INSPECTION, AND PACKAGING OF FORMED SEGMENTS

1. Surface Protection

The 2219-T37 aluminum gores are degreased in Type II trichloroethylene vapors at 188 ± 3°F. The part is lowered into the vapors and allowed to remain until the gore has reached the same temperature as the solvent.

Prior to dye penetrant inspection and conversion coating, the gores are flash etched in Turcoform etchant 13 to remove 0.0005 to 0.0006 inch on each side, thus cleaning the surface. After rinsing in tap water, the heavy black smut formed during flash etching is removed by submersing the gore in a desmutting solution similar to Wyandotte 2487-B at 12 to 16 ounces per gallon of solution at ambient temperature. The gore is then rinsed in tap water at ambient temperature.

The gore undergoes the following processing prior to dye inspection for cracks: (1) vapor degreasing, (2) alkaline cleaning, (3) rinse, (4) deoxidation, (5) rinse, and (6) drying. Before applying the dye penetrant, the gore must be completely dry and the temperature between 50 and 100°F. The dye penetrant, ZL-44B (Wichita) and ZL22 (MSFC), is applied by spraying in a manner to assure complete coverage of the part.

The ZE-3 (MSFC) emulsifier is sprayed on the part to ensure complete even coverage, beginning at the bottom and continuing to the top. The emulsifier remains on the part for a minimum of 2 minutes and a maximum of 2 1/2 minutes. The gore is then rinsed with water at 90 to 100°F, starting at the bottom and continuing upward. Rinsing must last at least five minutes. Boeing Witchita does not need an emulsifier with their ZL-44B dye penetrant.

Spray equipment is used to apply a uniform coat of developer to the gores, ZP-45 (Wichita) and ZP-5 (MSFC). The gores are dried at ambient temperature from 1/2 to 4 hours. An ultraviolet light is used to determine if any cracks or other defects exist.

To completely remove the dye penetrant before conversion coating, the gore is rinsed, by either spraying or dipping, in hot water (130-140°F) for at least 30 minutes. After rinsing, the gore is solvent cleaned by vapor degreasing with trichloroethylene at 188 ± 3°F. The gores are alkaline cleaned, rinsed, and deoxidized. The final rinse is in ambient temperature demineralized water until the pH of the aluminum surface is between 6 and 8. The gore remains at ambient temperature until dry.

Due to the high copper content of 2219 aluminum alloy, the gores are highly susceptible to corrosion. In an effort to prevent the corrosion tendency, the gores not requiring fittings added at MSFC are chromate conversion coated with either Alodine 1200 or Iridite 14-2. A protective film is obtained by submerging the gores in the conversion coating solution for 1 1/2 to 3 minutes at ambient temperature. After rinsing in tap water at ambient temperature, the gore is allowed to air dry at ambient temperature for a minimum of 24 hours before packaging.

2. Packaging

Gores shipped by truck or railroad car are normally wrapped in heat-sealed MIL-B-131 packaging material, which serves as a moisture barrier. Inside the sealed packaging material is a desiccant material, usually Silica Gel, which maintains a low relative humidity in the package. A humidity indicator is installed opposite the port inspection window, and the gores are placed in contoured nesting, complete with spacers and contour hold-downs. Careful handling of the gores is required, since the sealed MIL-B-131 packaging material should not be ruptured. A bad seal would disrupt the humidity control within the package, thus possibly causing corrosion.

G. CLEANING

Since temperatures above 150°F are detrimental to conversion coating, Iridite 14-2 or Alodine 1200 coating must be stripped from the weld area. The distance to strip the coating is directly proportional to the thickness of the gore. The typical stripping distance is 12 inches from the edge. The conversion coating is removed mechanically by either a rotary stainless steel wire brush or vapor blasting with glass beads. After removal of the conversion coating, the weld areas are wiped with solvent to remove all grease and foreign residue.

H. ROUTING AND WELDING OF HOLES IN GORE SEGMENTS

Routing of holes and welding of fittings are accomplished on one fixture at MSFC (Fig. 12). The holes are routed with a standard end mill cutter; standard TIG welds are made with a 2319 aluminum filler wire.

I. GORE SEGMENT AGING AND INSPECTION

Gore segments are aged in a restrained aging fixture (Fig. 13) to improve or maintain the contour. Aging of the gore and fitting assembly may be done in several cycles, depending upon the temper of the fittings (Table II). The purpose of this variation is to provide the maximum possible tensile strength and corrosive resistant properties for each type of gore assembly. After aging, the gores are dimensionally inspected in a concave fixture before being edge trimmed and welded together.

J. GORE SEGMENT PROTECTIVE TREATMENT AND STORAGE

After fusion welding, the weld areas which were previously stripped must be conversion coated. In order to obtain a fairly uniform coating, the weld areas must be wiped with solvent and deoxidized with a rotary stainless steel brush. Brush techniques are used to apply a conversion coating of Iridite 14-2 plus Cab-O-Sil thickening agent. The coating is allowed to dry at ambient temperature for a minimum of 24 hours before wrapping in MIL-B-131 packaging material and securing in wooden crates for storage.

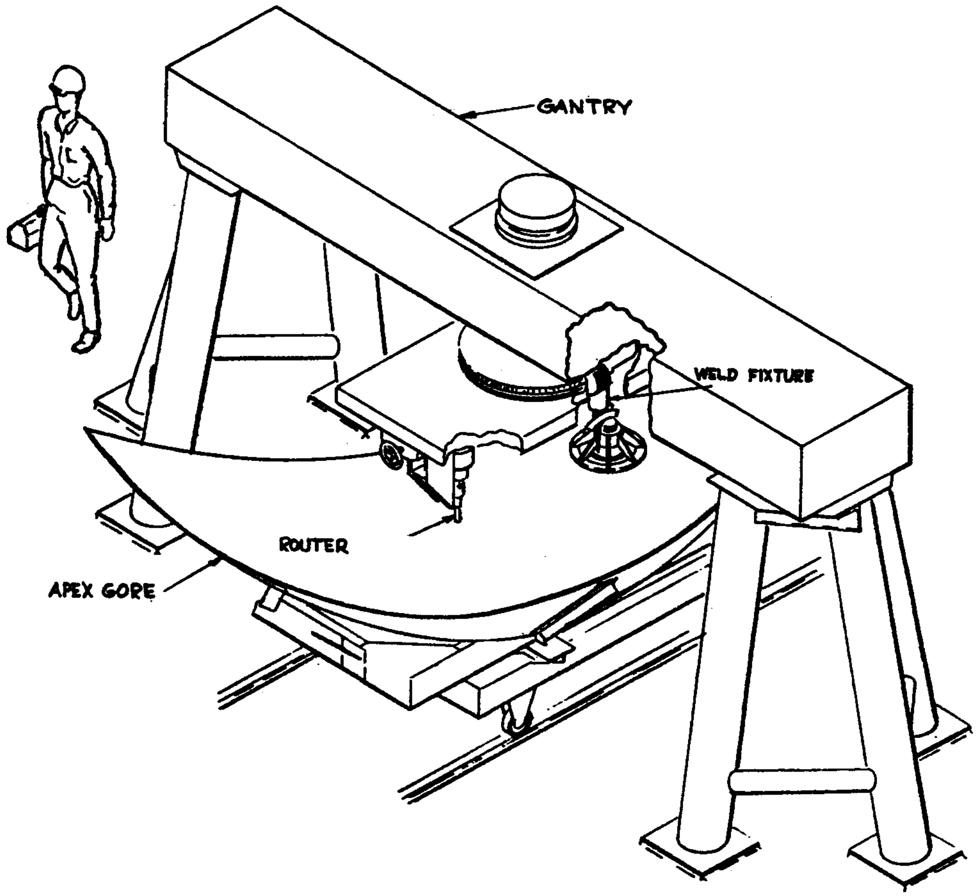

FIGURE 12. ROUTING APEX GORE AND WELDING FITTINGS

TABLE II. AGING CYCLES FOR GORE SEGMENT ASSEMBLIES

ASSEMBLY	AGING CYCLE
2219-T37 gore segment assemblies containing 2219-T4 or -T42 fittings regardless of other fittings present	24 hours @ 350°
2219-T37 gore segment assemblies containing fittings of only temper other than -T4, -T42 or -T37	18 hours @ 350°
2219-T37 gore segment assemblies containing only 2219-T37 fittings	24 hours @ 325°

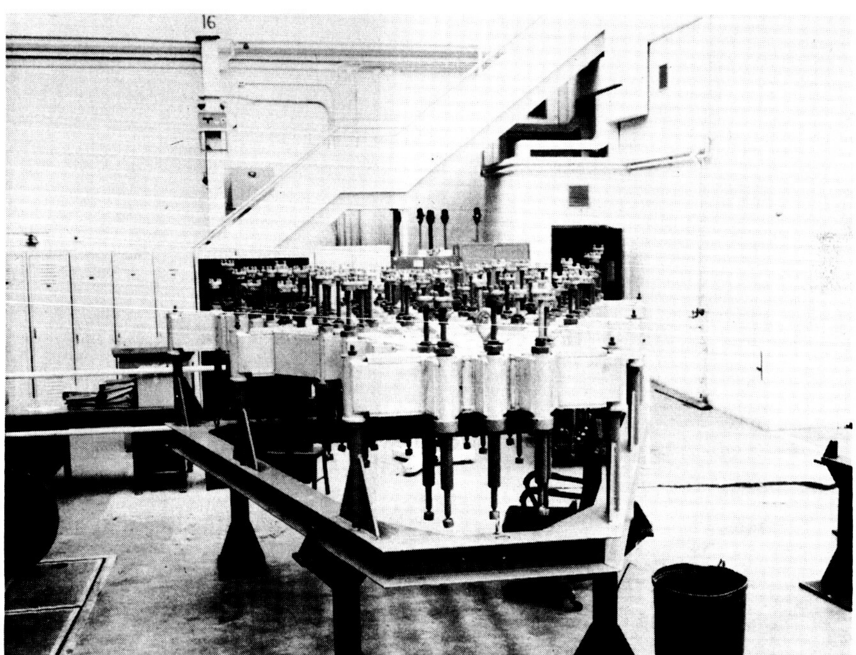

FIGURE 13. RESTRAINED AGING FIXTURE

SECTION III. ALUMINUM ALLOY 2014 GORES

A. RAW MATERIAL

Alloy 2014 is processed by the mills very similarly to 2219. The material is cast into billets, scalped, hot rolled, reheated, and rerolled in stages, inspected ultrasonically at 60 percent reduction, solution heat treated, straightened, and trimmed. It differs from alloy 2219 in that no cold work is necessary after solution heat treating to bring it to the desired temper. Solution heat treatment is performed at 950° F, followed by a water quench. NAA orders the material in the -T451 condition; Douglas orders the material in the -0 temper.

The material is supplied with a list of the mechanical properties and chemical composition. The mechanical properties include tensile tests in -0, -T4, and -T6, and bend tests, according to MB-0170-021 for NAA and MSFC-SPEC-104 for Douglas. The plate is marked and shipped to the customer. No special protective measures are necessary in shipping North American material, because of the surface milling of approximately 0.100" from each side. Douglas material has to be interleaved with paper for protection because the material is formed as purchased.

Upon receipt of the plate, the customer verifies the properties reported by the manufacturer and examines the material prior to machining or forming. Each plate is marked with an identifying number and all test data are carried with it through final inspection.

B. BLANK PREPARATION

North American Aviation receives thin blanks for the S-II in the -T451 condition to allow satisfactory machining with minimum distortion. The blanks are machined 0.100 inch on each side in a skin mill to a tolerance of ± .005 inch on the thickness. After machining, the blanks are marked again with the number they were assigned and cut to size by scribing to a template and sawing. No preform rolling is necessary before forming as the blanks are not as thick as those used on the S-IC. Waffle blanks are machined to a pattern that will form the desired waffle configuration after explosive forming. The theoretical pattern was developed by allowing a piece of warmed acrylic plastic to drape into a waffle contour tool. The grid intercepts of the pattern were then transferred to the plastic. The plastic was placed on a level surface and heated again until it flattened. The layout of this pattern was used for machining the waffle plates. The pattern was sufficiently accurate, although changes are to be made to provide wider edges for easier welding.

Douglas gores for the S-IVB are inspected prior to forming and all major surface defects are corrected as required. Material for bulge forming has to be free of any gouges, scratches, or imperfections. The material is scraped and/or polished until all blemishes are removed. Material for the stretch press operation does not have to be as critical and only severe imperfections are eliminated. Material containing excessive imperfections are rejected and returned to the vendor. No rolling is employed before forming since the maximum thickness in any gore material is 0.303". In stretching this thick material, it is chem-milled to 0.278" thickness, to reduce stretch press loading to a minimum. Subsequent re-orders will be issued for 0.278" material, which will eliminate future chem-milling.

C. GORE SEGMENT FORMING OPERATIONS

1. Explosive Forming

NAA explosive forms all gores except the forward common thin gores, which are stretch formed for the S-II. The dies are formed of massive 6 inch T-1 steel plate, which was incrementally formed to approximate contour, and are welded to an egg crate supporting framework. The cavity of the crate is filled with plastic to give additional mass. The overformed waffle die is an integral steel egg crate structure. The die is accurately machined to the desired final configuration and polished to mirror brightness. This finish is preserved by polishing the die lightly between each hit. If the die is to be exposed longer than 15 minutes, it is coated with a clear vinyl protective film or with a Turco film. All dies are made to net contour except the die for the final shot on the waffle segment which is made overform by 3/8 inch. Occasionally, a fourth shot in a net die is made to correct overforming of the part.

Five dies are used by NAA to form all segments (Fig. 14):

1. T-720049--Fwd. LH_2 Bulkhead
2. T-720050--Fwd. Common Bulkhead
3. T-7200048--Aft. Common Bulkhead and Aft. $L0_2$
4. T-720047--Waffle Segment
5. T-720047--Overform, Waffle Segment

The dies for the thin gores have a deep groove around the periphery, as seen in Figure 15. The blank is sealed with a PVC "0" ring inserted in this groove. The plate is sealed to the die face with zinc chromate tape, and a 1/2-inch thick blanket of epoxy plastic is placed over the workpiece. To form a thin gore, the blank is scribed and trimmed and laid on the die.

Air hoses are affixed to fittings at the corners of the blanket. As the die is lowered into the tank, the weight of the water forces the air out of the hoses. Also, the hoses prevent the admission of water to the surface of the part.

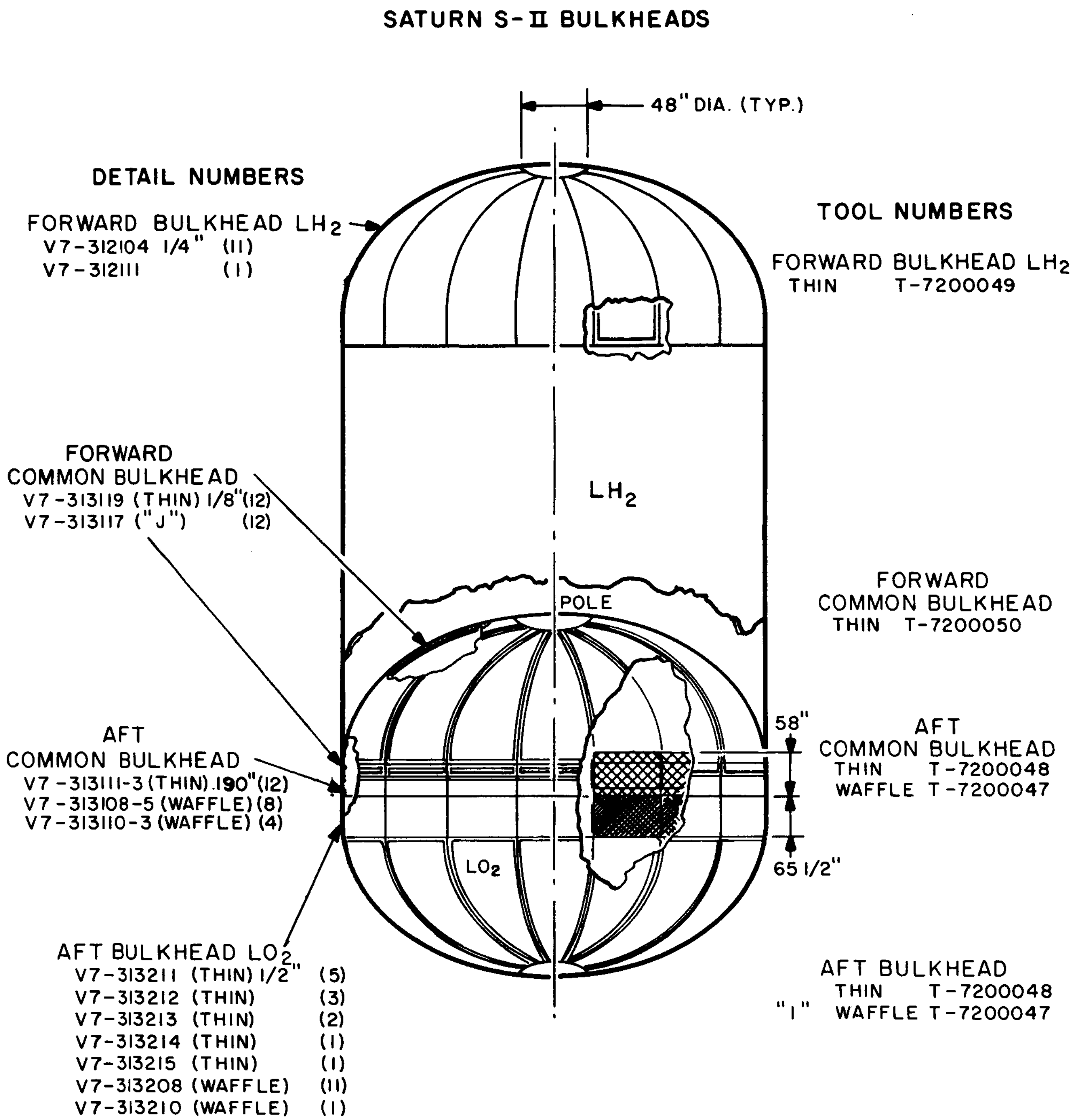

FIGURE 14. SATURN S-II BULKHEAD

The epoxy blanket was originally cast in a machine shop, but stray chips, which inadvertantly strayed into the blanket, caused marks on the part surface. This difficulty was remedied by enclosing the area where the blanket was cast. The draw ring is lowered into place, assembled, and secured. The area beneath the part is purged with dry nitrogen. Nitrogen between the part and the die has less tendency to heat the part when it is compressed during forming. This heating is intense enough when not controlled to cause localized melting of the part. Following the purging, a vacuum of 28 inches of mercury is drawn, and the standoff lines are affixed as in Figure 16.

Five layout tables set up at NAA, El Toro, have the pattern of each shot painted on them. A nylon fish net is laid over the table, and the explosive charge (Primacord) is loaded and tied to the net (Fig. 17). The strands are bound together where they cross to assure complete and even detonation. The charge together with the net is attached to the standoff lines. The entire assembly is then lowered into the tank where the charge is detonated. All gore sections are normally hit twice while in the -0 temper, then solution treated and quenched to -W temper, then hit a third and final time before chem milling. The part is removed from the die, cleaned, and inspected after every shot.

Waffle sections are formed in a similar manner, but with a few important differences. To prevent buckling of the part, a barrier rib is machined into the blank around the periphery and outside the trim line (Fig. 18). When the final trim operation is performed, the rib is completely removed. The preform is sprayed with a vinyl parting agent and filled with Cerrobend, which supports the ribs during forming. The part is laid into the die, covered with the epoxy blanket, strips of PVC, and a sheet of plastic film which is taped down (Fig. 19 and 20). The PVC serves as a path by which air under the polyethylene film may escape. The first forming operation is made by means of the vacuum only. Since forming of approximately 1 1/2 inches is accomplished in this operation, the Cerrobend cracks and must be removed and recast. The panel is placed, convex side upward, under a loose fitting steam hood. The circulating steam causes the aluminum to expand, releasing the Cerrobend into a tray beneath the part. This operation is also performed after each of the explosive operations. The panel is put back on the die and sealed as before. No draw rings are used; the vacuum is the only hold-down employed. One explosive operation is performed on the net contour die, followed by one on the overform die. Conformity to contour is checked by placing small amounts of zinc chromate paste in the bottom of the die and lowering the part onto it. After removing the part, the paste is checked to see how much flattening occurred. An egg crate fixture is also used to check the contour of the explosive formed waffles.

FIGURE 15. INSTALLATION OF PVC "0" RING

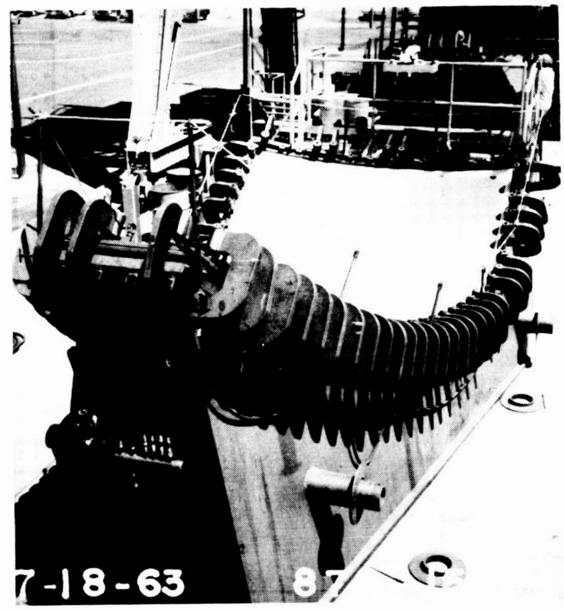

FIGURE 16. STANDOFF LINES IN PLACE

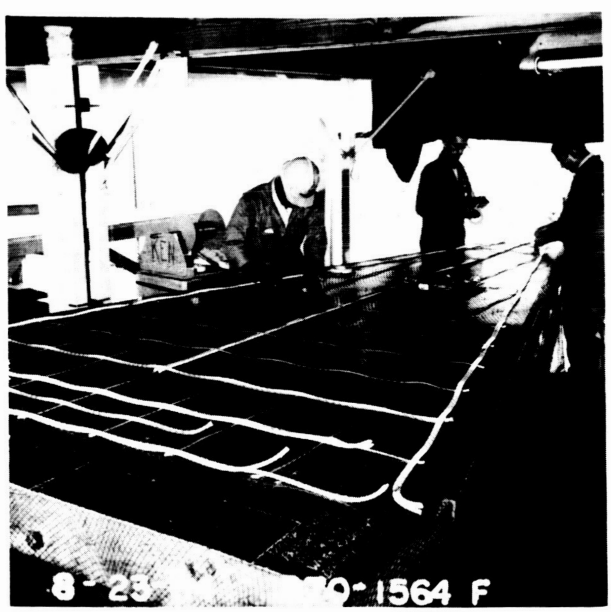

FIGURE 17. LAYOUT OF EXPLOSIVE CHARGE

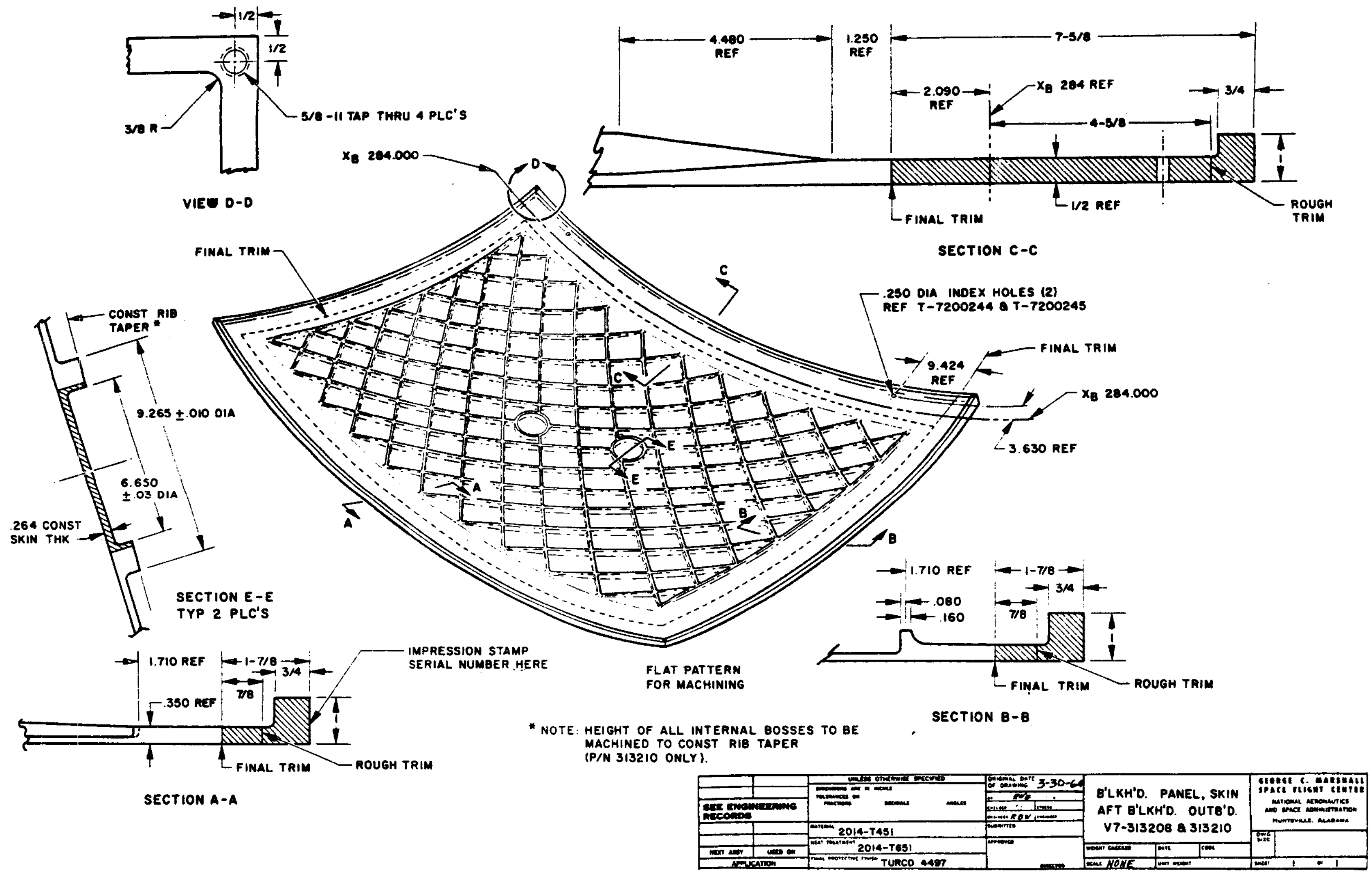

FIGURE 18. WAFFLE SEGMENT SHOWING BARRIER RIB

FIGURE 19. INSTALLATION OF EPOXY BLANKET

FIGURE 20. VACUUM CHECKOUT

The original purpose of the blanket was to protect the surface of the workpiece during forming. However, an additional advantage was realized--the neutral bending axis of the workpiece was shifted. Because of the great velocity of forming, there is no slip along the interface between the blanket and the workpiece; that is, the two behave as though they were a single piece of material. In Figure 21 the neutral axis of the material is X-X.

During forming, outer fibers are in tension, inner fibers are in compression, and the neutral axis is unstrained. Assuming a specimen thickness of .300 inch and a bend radius of 100 inches, for the outer fibers,

$$\% \text{ elongation} = \frac{1/2T}{R-1/2T} \times 100 = \frac{.150}{99.850} \times 100 = 0.15\%$$

The small amount of strain is not enough to exceed the yield strength of the material, so springback would eliminate any forming done.

Adding a 1/2-inch epoxy blanket to the back, shifts the neutral axis beneath the part. Thus, for the outer fibers,

$$\% \text{ elongation} = \frac{.400}{99.600} \times 100 = .4\%$$

By adding the blanket, the fibers have been stretched into plastic deformation, reducing springback. For this reason, the epoxy blanket actually causes the part to form more readily and more accurately.

Stringent quality control must be practiced to achieve desired tolerances. Water in the explosive forming pits is constantly filtered and changed regularly. Workpiece and tool surfaces are carefully covered with protective coatings to prevent corrosion.

2. Hydraulic Bulge Forming

The original design concept was to form two gores of either forward or aft common bulkhead in one operation. The die, therefore, was made to accommodate nesting of these two gores. Subsequent development eliminated this design concept. The forming cavity is in the base of the die and the forming fluid is contained in a neoprene rubber bag. This bag approach has not been too satisfactory, because of the pressures required and the inability to contain the bag within the entire perimeter of the punch. Any voids or improper sealing causes the bag to rupture before the forming pressure is obtained. Because of the bag size, these leaks are extremely difficult to patch and vulcanize. An excessive amount of rework would be necessary to eliminate the bladder and change over to a bagless bulge die. It is anticipated that bulge forming will be phased out as soon as all the T-3 material has been formed and all future gores will be stretch formed.

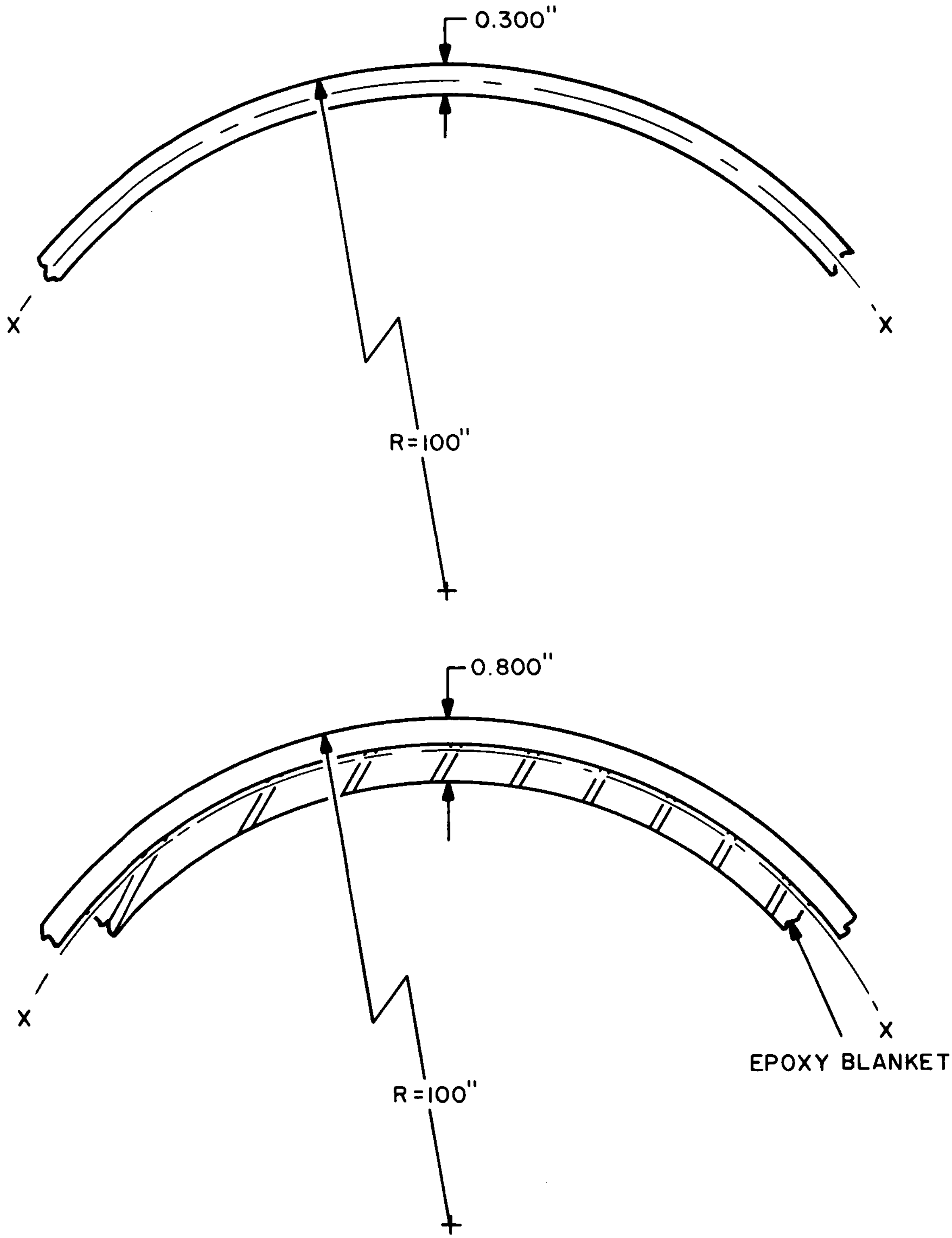

FIGURE 21. USE OF EPOXY BLANKET FOR EXPLOSIVE FORMING

3. Stretch Forming (Fig. 22)

Although Douglas had originally planned to use stretch forming as a back-up process, it now accounts for virturally all of the gores produced for the S-IV and the S-IVB. Douglas also stretch forms the forward common thin gores for North American's S-II.

A Sheridan-Gray stretch forming press at the Douglas -El Segundo Division, was rated at 500 tons, main ram pressure. This press was formerly used to form the S-IV gore segments. When this Douglas location was closed, the press was transferred to the Santa Monica Division, reworked and modified so that the rated 500 tons could be obtained. With this rework, it was possible to form the thickest gores by increasing the pressure from 2,000 PSI to 4,000 PSI. The pressure increase transmitted an extremely marginal stress in the jaw castings. A modification plan was submitted to replace the castings and other weak points of the machine to obtain a pressure increase of 750 tons. Although the forming pressure required for the 0.303" thick material will still exceed this 750 tons, it is believed that the pressure will still be well within the allowable marginal limits. To also assist in decreasing the required forming pressure, the skins are presently chem-milled to 0.278" material thickness. Future purchased material will be obtained to the 0.278" thickness.

The 2014-0 material is placed in the machine and gripped by the two long jaws on either side of the die table. These jaws are mounted on a sliding yoke with tension cylinders at each end of the jaw. The material is loaded to a preset elongation by means of hydraulic tension cylinders beneath the floor. The cylinders are pressurized to a predetermined level and held constant. The die table between the jaws is raised into the workpiece. The jaws pivot about a shaft, which permits loading the part in pure tension throughout the forming cycle. The cylinders allow the jaws to slip inward along the yoke while maintaining a constant load on the material. In this manner, pure stretch wrap forming is accomplished. The jaws may be positioned at any angle from horizontal to vertical and changed by means of hydraulic cylinders.

Two mandrels are used to form all S-IVB gore segments. One mandral forms gores for the forward common dome; the other forms the three additional domes. The die bases are steel plates, drilled and tapped for mounting onto the die table. These bases also contain sheet metal type cores that reduce the amount of Kirksite required to a minimum, thus reducing the overall weight of the tool. The Kirksite is poured around and onto these steel cores and thus locked to the base plate. One of these dies contains 40,000 pounds of Kirksite and the other 60,000 pounds. The largest die has a base of 102" by 152". The faces of the

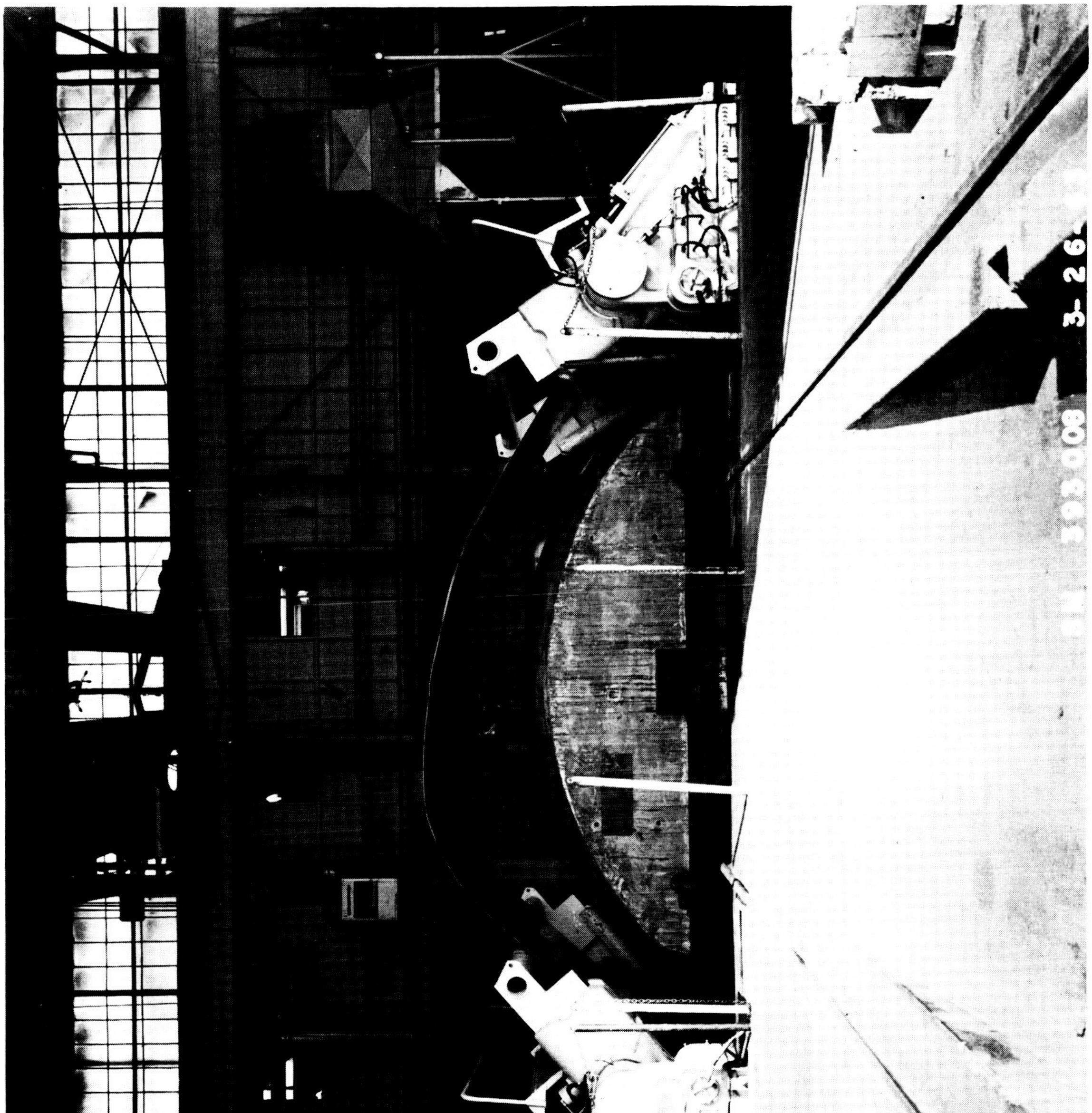

FIGURE 22. STRETCH FORMING PRESS

Kirksite die were bored with a recess of approximately 3/4" depth. This recess was used to contain the plastic facings which were poured to the exact contour required and which eliminated all subsequent machining of the die surface. Furane 4-B plastic resin was used for making the plastic face.

Thin gore blanks are loaded into the machine in the -0 temper and stretched to 90-95 percent of final contour. At this time, the stretch forming has hardened the material to such an extent that it is removed for heat treating and quenching to the -W condition. Immediately after quenching, the material is stretched to final contour.

The annealing and heat treat ovens have a maximum opening of 42"; since the depth of the stretch formed gore exceeds these provisions, it had to be modified to allow heat treating of the formed part. This was accomplished by reverse forming the ends of the material after the preliminary or initial stretch was completed. An attachment was designed for the jaws of the Sheridan Gray press, which was used to reverse form the material into a "W" shape. After solution heat treating, the ends are reversed to the original contour. This is allowable because of the final stretch is done on the green T-4 condition after quench.

The material for the heaviest gore is chem milled to .275-.280 inch and stretched to approximately 60 percent of the finish contour. The part is given a stress relief anneal, stretched to 100 percent contour, and solution heat treated. The segment is returned to the stretch press for final sizing in the -W temper. After sizing, the segment is removed and trimmed.

Bulge forming causes approximately 10 percent thinout maximum, while stretch forming causes only 5 to 6 percent.

D. GORE SEGMENT TRIMMING AND SIZING

After all forming operations are complete at both NAA and Douglas, the part is placed on a concave rough trim fixture and trimmed to approximately 2 1/2 inches outside the final trim line. After trimming, NAA places the segments in a restraining fixture for aging to T-651 temperature. Douglas is in the process of developing age sizing on gores that do not come up to the required contour. North American has attempted aging on a Glasrock fixture, but the temperature could not be adequately controlled. Prior to aging, every effort is made at NAA to correct contour deviations. For contour inspection, a concave fixture is utilized for all parts except the forward common bulkhead, which is inspected on a convex fixture. The gores for the forward and aft domes are restrained in the checking fixture around the perophery by means of lead blocks weighing 2 lbs.

per linear inch. The forward common bulkhead inspection method had not been resolved at the time of this writing. Since the assembly of the completed bulkhead will be done under pressure, NAA received permission to inspect the forward common gores at a vacuum of 8 psi. Aft common gore inspection at 2 psi vacuum has already been approved and is in use.

The amount of correction attainable by restrained aging is less predictable with alloy 2014 than with alloy 2219. Pre-age contour correction is performed by three methods--Yoder hammer, arbor press, and a small hand-operated press. Thin gores are usually planished with the Yoder hammer or formed with the small hand-operated press to correct contour deviations. Waffle segments are corrected in the arbor press in the same manner as at Boeing Wichita, except the maximum pressure employed is defined. The hydraulic line pressure is limited to prevent damaging of the panels during rework. Should the contour deviation require pressures exceeding the maximum allowable pressure, other methods must be employed to correct the contour. Correction of one waffle normally requires a crew of four men. If contour deviation exceeds 1/16 inch, the waffle sections may be sent back to the explosive forming facility for a sizing re-strike.

After correction of contour, the part is placed in the heat treat restraining fixture. The part is clamped on the periphery, outside the final trim line. The fixtures for aging the waffles and thin gores are made one inch overform in the center which fairs to net contour at the edges. Screws with contour pads or shoes are tightened to contact the side of the gore away from the overform. The screws beneath the areas needing correcting are advanced twice the desired correction, thus allowing 50 percent springback. (For very slight corrections, the screws are advanced three times the desired correction.) After aging, the part is removed and checked a final time for contour deviations.

Stretch formed segments at Douglas require very little pre-age corrective forming. The heat treat fixture is composed of simple restraining concave and convex tools. The gores are placed in the fixture and clamped by bars across the back. All surfaces of contact are protected by asbestos. Further correction, if required, is accomplished by hand planishing.

Douglas also has facilities for explosive forming and sizing; however, Douglas is not presently using this method to form or size gore segments.

E. CHEMICAL MILLING OF FORMED SECTIONS

1. Requirements

The S-II gores are formed at NAA and chemically milled by three different contractors; Chemtronics, San Diego; Anodite, and Chemical Contour, Los Angeles. Chemtronics and Anodite chemically mill the aft common and forward LH_2 gores. The gores are tapered smoothly by lowering the parts into the etchant at slow speeds. Thicknesses of the gores range from .500 to .030 inch with typical tolerances of ±.005 inch.

The S-IVB gores, formed and chemically milled at Douglas, are designed in waffle and stepped patterns to give sufficient strength with minimum weight. The required tolerance for these gores is +.010 to -.005 inch, thus requiring minimum handwork operations.

2. Chemical Milling Operations

The gores for the S-II and S-IVB are initially cleaned for masking as follows: (1) Vapor degreased, (2) alkaline cleaned, (3) rinsed, (4) deoxidized, (5) rinsed, and (6) dried. After removal of burrs and sharp edges from the gores, a chemically inert maskant is applied in several coats. Chemical Contour, one of NAA's three contractors to chemically mill formed gores, used a clear maskant, Organoceram 2020.

A template is used for scribing the chemical milling design into the maskant; the maskant is removed from areas to be milled by carefully pulling from the edge to the center of the scribed areas. All foreign matter and maskant residue are removed from the bare metal surface by wiping with solvent. Caution is taken to prevent solvent contact with the remaining maskant. Lead tape is applied over the edges of the maskant for protection from handling.

Chemical contour, Anadite, and Chemtronics use proprietory chemical milling solutions. Temperatures, concentrations, solution controls, and milling procedures are unknown to MSFC at this time. The S-IVB and the S-II gores are chemically milled in the T6 or T651 temper after forming.

DAC uses Turcoform etchant 9H in their milling operations. This solution is used at a concentration of 15 oz/gal of etchant and 10 oz/gal inhibitor at a temperature of 190 ± 5°F.

Chemical Milling high copper aluminum alloys causes a heavy black smut to form. The smut should not be allowed to cool before removal. DAC's solution of 10 lbs/gal chromic acid and 10 percent by volume, HNO_3 is commonly used to remove the smut. The gores are submerged until all smut is removed, and dried at ambient temperature.

The maskant is removed from the gore by hand operations; however, the maskant can be initially loosened by submerging the gore into trichloroethylene vapors at 188 ± 3°F. Sludge or smut remaining on the gore after demasking is removed by repeating the desmutting procedure above.

3. Problem Areas with 2014 Gores

Pits and foreign matter forced in the metal surface during explosive forming of the S-II gores have been a cause of selective attack, and uneven etching. To resolve the problem, the following protective measures are taken: (1) buffing the explosive forming die, (2) coating die with Turco 4497, a strippable coating, when not in use, (3) coating the parts with Turco 4497 and steam cleaning prior to forming, and (4) connecting a filter system to the water. Metal chips were induced into the S-II gores by a contaminated epoxy blanket surrounding the gore during explosive forming. Cleaning the blanket eliminated this problem. Occasional over-etching and waviness in weld land areas existed on several S-II gore sections. Adjustments in concentrations and temperature have almost completely eliminated this problem. Distortion effects were observed after chemical milling explosively formed S-II gores to a .125-inch thickness; however, no distortion was observed at a .190-inch thickness.

4. Future Development Programs

As parts are formed to a greater degree and chemical milling increases to greater depths, new techniques of a chemical-mechanical combination removal should be investigated. Approximately 90 percent could be removed with etchants and the remaining 10 percent would need to be removed by mechanical means. Douglas has recently chem-milled S-IVB skin sections, utilizing these methods. They have successfully used this on 5 skins as an assist in making up the lost schedule time of the skin milling machine.

A new chemical sizing or polishing operation should be investigated to bring the gores within the desired tolerances. To accomplish this task, two chemical milling tanks may be required. The present method used to obtain gores within desired tolerances requires a large amount of handwork, which can be very expensive.

5. Inspection of Chemically Milled Gores

The inspection criteria necessary to determine the quality or acceptability of a processed gore are the resulting surface finish and dimensional tolerances. The thickness is checked at Douglas by a "C" type yoke dial indicator, but NAA uses a Vidigage. S-IVB gores require a tolerance of +0.010 inch -0.005 inch whereas S-II gores require ±0.005 inch. The maximum surface roughness of 125 RMS microinches can be determined utilizing a Profilometer, a Talysurf, or a Surfindicator.

F. PROTECTION, INSPECTION, AND PACKAGING OF FORMED SEGMENTS

1. Surface Protection

The 2014 aluminum gores are degreased in Type II trichloroethylene vapors at 188 + 3°F. The gores are slowly lowered into the vapors until they have reached the same temperature as the solvent. When this occurs, the gores are slowly removed.

Prior to dye penetrant inspection, the aluminum oxide film on the gores is removed as follows: (1) alkaline clean, (2) water rinse, (3) deoxidize, (4) nitric acid dip, and (5) water rinse.

After deoxidation the gores are dye penetrant inspected for cracks. DAC uses a two component system, SKL-4, manufactured by Magnaflux. NAA uses a three component system from Magnaflux composed of ZL-2 penetrant, ZE-4 emulsifier, and ZP-4A developer. NAA also inspects the part visually by applying a Pin Strip Process. This process consists of application of a red dye (PIR), water wash, application of developer (DIW), application of clear plastic (DZC), and followed by a visual inspection for cracks. After the plastic is removed, NAA conversion coats the parts with Alodine 1200 for corrosion protection.

DAC applies Type I (chromic acid) anodize to the S-IVB gores for corrosion protection. Type I anodize is produced by submerging the gore in a bath of 5 percent (vol) chromic acid at 95 ± 5°F and slowly applying from 0 to 40 volts during a five minute period. The gore remains in the solution for a minimum of 30 minutes at a minimum current density of one ampere per square foot. Afterwards, the gores are rinsed in cold, demineralized water before sealing in water at 180 to 212°F for five minutes. The water maintains a pH of 4 to 6 by addition of chromic acid or sodium dichromate.

NAA conversion coats with Alodine 1200 solution. This protective film is obtained by submerging the gore in a conversion coating solution, after deoxidation, for 1 1/2 to 3 minutes at ambient temperature. After rinsing in tap water, the coating is dried at ambient temperature for a minimum of 24 hours.

Since the majority of NAA's work is done by outside contracts, the S-II gores must be transported to and from NAA several times. During shipment it is necessary to protect the gore from abrasion and corrosion. Turco 4497, a blue strippable coating, is applied to the gore in 5 coats for protection during shipment. The coating is applied with DeVilbiss Airless spray equipment at a maximum thickness of .005 inch. Spray application of this coating presents a fire hazard and strict regulations are necessary during application. NAA requires an area to be roped off, no smoking signs posted, and a guard to be stationed at the area to enforce safety regulations. Upon receipt, the gores are stripped of their coating and inspected for damage during shipping. The gores are stored outside in wooden boxes, insulated with polyurethane foam and covered with a tarpaulin.

G. CLEANING

NAA, who conversion coats their 2014 S-II gores, must strip the conversion coating from the weld edges prior to welding. After removal of the conversion coating, the weld areas are solvent wiped to remove all greases and foreign residue.

DAC, who Type I anodizes their 2014 S-IVB gores, needs to remove this thick oxide coating prior to welding. The anodize is removed 1 1/2 to 2 inches from the edge with Pasagell 101. The cleaned weld area is rinsed with water at ambient temperature and air dried.

H. GORE SEGMENT PROTECTIVE TREATMENT AND STORAGE

After fusion welding, both the S-II gores and the S-IVB gores are conversion coated in the weld areas. Prior to application of the conversion coating, the weld areas are solvent wiped and deoxidized. Brush techniques are used to apply a conversion coating of Alodine 1200. The coating is allowed to dry at ambient temperature for a minimum of 24 hours before placing the S-II gores in a wooden crate insulated with polyethylene.

CONCLUSIONS

SUMMARIZATION CHART FOR ALLOY 2219 ON S-IC STAGE

PROCESS	PRESENT EQUIPMENT LIMITATIONS			TOOLING COST	TOOL LEAD TIME	PROCESS DEVELOPMENT TIME	PROCESS TIME/PART	RESIDUAL STRESS DISTRIBUTION	TOLERANCE OBTAINABLE		REPRO-DUCIBILITY	INSPECTION METHODS
	TONNAGE	BLANK SIZE	PART CONFIGURATION						CONTOUR	THICKNESS		
BULGE FORMING	16.5 K	0.800" x 115" x 230"	Large Compound Radii	$250,000	3-5 mos	2-4 mos	1-3 hrs	multi directional	$\pm \frac{1}{8}$"	± 0.008"	Good	Contour and Vidigage
EXPLOSIVE FORMING	X	Unlim-ited	Large Compound Radii	$40-60,000	3-5 mos	2-4 mos	2-6 hrs	multi directional	Not Fully Developed		Good	Contour and Vidigage
INCREMENTAL FORMING	3000	Unlim-ited	Large Compound Radii	$500-1000	3 wks	4 wks	25-50 hrs	multi directional	$\pm \frac{1}{4}$"	± 0.010"	Good	Contour and Vidigage

CHEMICAL MILLING

SURFACE CONDITION - 100 to 125 RMS

FILLET CONDITION - Good - No End Grain Attack

LINE DEFINITION - Good

THICKNESS CONTROL - Fair - Handwork Required

ETCH RATE - 0.0006 to 0.001 inches/min

SURFACE COATS

CORROSION PROTECTION - Iridite 14-2 Conversion Coat

METHOD OF APPLICATION - Spray Type or immersion

METHOD OF REPAIR - Brush Application of Iridite 14-2 with Cab-O-Sil

RECOMMENDATIONS FOR PRESENT AND FUTURE PROJECTS:

CONCLUSIONS

SUMMARIZATION CHART FOR ALLOY 2014 on S-V

PROCESS	PRESENT EQUIPMENT LIMITATIONS			TOOLING COST	TOOL LEAD TIME	PROCESS DEVELOPMENT TIME	PROCESS TIME/PART	RESIDUAL STRESS DISTRIBUTION	TOLERANCE OBTAINABLE		REPRO-DUCIBILITY	INSPECTION METHODS
	TONNAGE	BLANK SIZE	CONFIGURATION						CONTOUR	THICKNESS		
BULGE FORMING	16,500	115" x 230"	Large Compound Radii	$125,000	3-5 mos	2-4 months	1-3 hrs	multi directional	Not Fully Developed		Good	Contour and Vidigage
EXPLOSIVE FORMING	X	Unlim-ited	Large Compound Radii	$160,000	3-5 mos	2-4 months	4-8 hrs	multi directional	$\frac{1}{16}$"	± 0.008	Good	Contour and Vidigage
INCREMENTAL FORMING	3000	Unlim-ited	Large Compound Radii	$500-1000	3 wks	4 wks	25-50 hrs	multi directional	$\frac{1}{8}$	± 0.010"	Good	Contour and Vidigage
STRETCH FORMING	750 (Main Ram)	0.303" Max Thickness	Compound Contours and Curves	$12-20,000	3-5 mos	1-2 months	$1\frac{1}{2}$ hrs	uni directional	$\frac{1}{32}$	± 0.008"	Excellent	Contour and Vidigage

CHEMICAL MILLING

SURFACE CONDITION - 100 - 125 RMS

FILLET CONDITION - Good

LINE DEFINITION - Fair

THICKNESS CONTROL - Good-Minimum Handwork Required

ETCH RATE - Approx 0.001 inches/min

SURFACE COATS

CORROSION PROTECTION - Chromic Acid Anodize or Alodine 1200 Conversion Coating

METHOD OF APPLICATION - Spray Type or immersion

METHOD OF REPAIR - Brush Application of Alodine 1200

RECOMMENDATIONS FOR PRESENT AND FUTURE PROJECTS:

NASA TM X-53033 APPROVAL April 22, 1964

PROCESSING OF BULKHEAD SEGMENTS FOR SATURN V VEHICLES

The information is this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for Technical accuracy.

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